Volume 56 | September, 1942 | $4.00 a Year
Number 3 | Pages 265-403 | $1.25 a Number

JOURNAL

OF THE

New England Water Works Association

ISSUED QUARTERLY

Published by
THE NEW ENGLAND WATER WORKS ASSOCIATION
613 Statler Building, Boston, Mass.

Entered as second-class matter September 23, 1903, at the Post Office at Boston, Mass., under Act of Congress of March 3, 1879
Copyright, 1942, by the New England Water Works Association

OFFICERS
OF THE
New England Water Works Association
1941-1942

PRESIDENT

FRANCIS H. KINGSBURY, Senior Sanitary Engineer, Massachusetts Department of Public Health, Boston, Mass.
(Term expires September, 1942)

VICE-PRESIDENTS

HAROLD L. BRIGHAM, Superintendent, Water & Sewage Commission, Marlboro, Mass.
(Term expires September, 1942)

HORACE L. CLARK, Superintendent, Water District, Sanford, Maine.
(Term expires September, 1943)

DIRECTORS

KARL R. KENNISON, Chief Engineer, Metropolitan District Water Supply Commission, Boston, Mass.
(Term expires September, 1942)

HAROLD W. GRISWOLD, Deputy Manager and Deputy Chief Engineer, Water Bureau, Metropolitan District, Hartford, Conn.
(Term expires September, 1943)

ARTHUR L. SHAW, Partner, Metcalf & Eddy, Consulting Engineers, Boston, Mass.
(Term expires September, 1944)

PAST PRESIDENTS

PERCY A. SHAW, Superintendent and Engineer, Water Works, Manchester, N. H.
LELAND G. CARLTON, Superintendent, Municipal Water Works, Springfield, Mass.

SECRETARY

FRANK J. GIFFORD, Cambridge, Mass.

TREASURER

FRANK J. GIFFORD, Cambridge, Mass.

EDITOR

GORDON M. FAIR, 112 Pierce Hall, Harvard University, Cambridge, Mass.

THE Association was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of 800 men. Its membership is divided into six classes, viz.:

A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

A Junior shall be not less than eighteen years nor more than twenty-five years of age, a student or connected with water supply work.

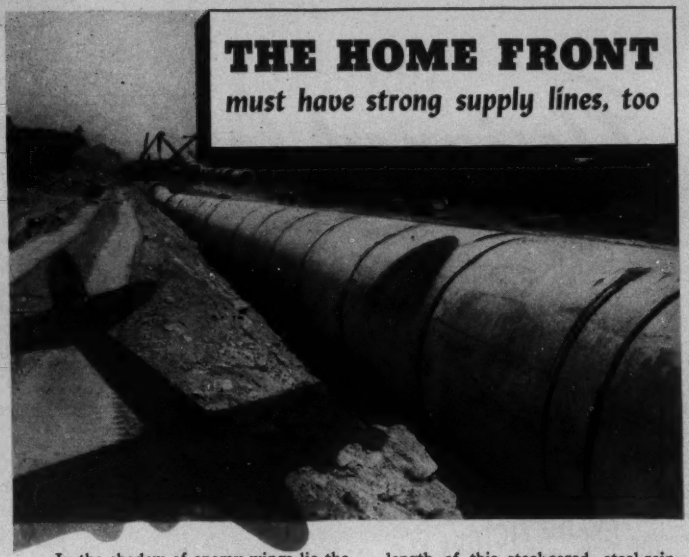
An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

A Corporate Member shall be either a Water Board, Commission, Company or Municipal Corporation.

The initiation fees and annual dues are as follows:

	Initiation Fees		*Annual Dues*
Members	$ 3.00	Members	$ 6.00
Juniors	1.00	Juniors	3.00
Associates	10.00	Associates	20.00
Corporate Members	10.00	Corporate Members	10.00

This Association has at least eight regular meetings each year, of which five are held in Boston, one in northern New England, one in southern New England, and one, the annual convention, held in September on such date as the Executive Committee may designate.



THE HOME FRONT

must have strong supply lines, too

In the shadow of enemy wings lie the water supply lines in a thriving community. First an aerial reconnaissance photograph. Later a target!

Today, on the home front, it is the duty of every responsible official to select the strongest pipe lines under the sun. Lock Joint Reinforced Concrete Pipe is included in the specifications for the majority of all large diameter water pipe contracts in the United States. Resistance to great shock, heavy loads and vibration is built into each length of this steel-cored, steel-reinforced, concrete walled pipe. Ability to withstand earth movement and deformation is assured by the self-caulking flexible expansion joints. The construction and design make Lock Joint Pipe your safest, surest investment today—yet Lock Joint Pipe uses less of those essential materials so necessary to our War Effort. Whether your project is large or small, your 'phone call, telegram, cable or letter to any of our offices will bring a prompt reply.

SCOPE OF SERVICES

Lock Joint Pipe Company specializes in the manufacture and installation of Reinforced Concrete Pressure Pipe for Water Supply Mains as well as Concrete Pipe of all types for Sanitary Sewers, Storm Drains, Culverts and Subaqueous lines.

LOCK JOINT PIPE COMPANY

Established 1905

AMPERE, NEW JERSEY

Denver, Colo. • Chicago, Ill. • Kenilworth, N. J. • Kansas City, Mo. • Rock Island, Ill. White Plains, N. Y. • Valley Park, Mo. Cleveland, Ohio • Hartford, Conn. Navarre, Ohio

LOCK JOINT

Reinforced Concrete

PRESSURE PIPE

Table of Contents

PAGE

Guarding Public Water Supplies. By Lewis E. Moore 265

Training and Organization of Technical Consultants to Deal with Chemical and Bacterial Contamination. By Leon A. Bradley 271

Chemical Contamination of Water Supplies. By Lazarus Rubin 276

Instruction in Water Bacteriology at the Massachusetts Decontamination School. By Joseph A. McCarthy 288

The War Department Civilian Protection School at Amherst College, Amherst, Mass. By Henry C. Hall 294

Water—A Critical War Material. By Arthur E. Gorman 302

War Time Problems in the Portland Water District. By F. J. Reny .. 309

Studies on the Removal of Iron and Manganese from Water. By Edward W. Moore and Ernest A. Snow, Jr. 320

Rockport, Mass.—The Evolution of a Small Water Works System. By E. Sherman Chase and George C. Houser 335

Salt Content of Wells in Massachusetts Affected by the Tidal Wave and Hurricane of 1938. By Vincent M. Hynes 355

Determination by Statistical Methods of the Average Service Life of 6-Inch Cast-Iron Water Mains in Brooklyn, New York. By A. V. Ruggles 361

A Statistical Method for the Investigation of Average Service Life. By C. Beverley Benson 390

Proceedings:

Sixty-first Annual Convention 397

New England Water Works Association
ORGANIZED 1882

VOL. LVI September, 1942 No. 3

This Association, as a body, is not responsible for the statements or opinions of any of its members

GUARDING PUBLIC WATER SUPPLIES

BY LEWIS E. MOORE*

[*Read September 16, 1942*]

The guarding of utilities in a country at war is not a simple matter. To guard everything would occupy the full time of the whole Army and leave no one available for the offensive which is necessary for victory. In this paper, I shall confine myself to the subject that is nearest (and perhaps dearest) to the reader of this JOURNAL; in other words, to water works and their guarding.

Hazards. There are at least three ways by which water supplies may be damaged: (1) artillery fire; (2) bombing from planes; and (3) sabotage. The first can only occur in theatres of active operations and need not concern the reader particularly. There is nothing water works operators can do about it, except to repair damage as expeditiously as hostilities permit.

Bombing from planes is a hazard that may be met with in New England. There is little that can be done about it except to be prepared to repair promptly damage that may be caused. Water mains will probably be broken. Fortunately, breaks in mains occur with sufficient frequency so that all water departments are set up to repair them expeditiously by the use of such materials and equipment as may be available. One of the very likely hazards accompanying such a break is caused by the juxtaposition of water and sewer pipes under our streets. A bomb that breaks one will probably break the other at the same location. A probable result will be that before the water pipe can be repaired some sewage will have entered it. The only practical precautions the author can think of are to flush pipes beyond the break thoroughly through street hydrants and to chlorinate the mains in the vicinity in accordance with the instructions that have already been issued by the state departments of health. Customers located beyond

*Colonel, Corps of Engineers, U. S. Army, Headquarters First Service Command, Boston, Mass.

the break should be warned to boil all drinking water until the supply is declared to be safe by the health board.

To determine what can be done to minimize the effect of a raid, we must consider what forms damage may take.

If a bomb lands on an aqueduct, and more particularly at a point where the aqueduct is on a fill, the flow of water from the broken aqueduct will enormously increase the damage done by the bomb. The answer to that is to shut off the flow of water at the entrance to the aqueduct as soon as the actual air-raid warning is received. This will limit the amount of water escaping through a break to the water actually in the aqueduct at the moment the break occurs. The reservoir at the exit to the aqueduct will generally have sufficient capacity to carry on during the raid. Bear in mind that it must carry on in any case until the break is repaired and that the slight additional time necessary because of the shutdown before the break occurs will be regained many fold in the reduced amount of repairs because there was no flow of water to increase the damage caused by the bomb.

It is a remote possibility that a dam might be wrecked by a bomb. It would require a very lucky hit to accomplish this result. The dam of thin section is both the easiest to damage and by far the hardest to hit in a vital spot. The thicker the dam, the harder it is to damage and the easier it is to hit. For once, the percentage of risk favors the owner. If the dam is located on one of the upper ones of a chain of reservoirs, its destruction might do no more harm than to reduce the amount of water in storage. As to damage to property in the valley below the dam, it should be remembered that such damage may be little if the channel restrictions affecting the flow of water released are great.

Another form that damage may take is for a bomb to strike a boiler house or engine room. A bomb striking a boiler and puncturing it may have its force enormously augmented by the steam in the boiler. In other words, a boiler explosion is added to a bomb explosion, with gaudy results. The only cure is to install electric or Diesel pumps as quickly as possible afterwards and in the meantime to reach as much of the distribution system as possible by gravity feed.

A bomb in an engine room may make it entirely inoperative, or it may not. In any case, the damage to the machinery may be increased greatly if the machinery is moving at the time of the explosion. Dam-

aged moving machinery will further damage itself by its continued motion. The engines should be shut down when the first warning arrives and dependence placed upon such reservoir capacity as may exist. If direct pumping is used with no reservoir or standpipe beyond the engines, it may be necessary to continue to run the engines and to hope. After all, percentages will be with the water works. If damage to chlorinating equipment occurs, then an immediate request should be made to the state "water supply coördinator" or state department of health for emergency equipment.

Damage to pumping machinery by bombing cannot be prevented, except by keeping the bomber away. Tests seem to indicate that a concrete slab 7 ft. thick would be required to stop a 1000-lb. bomb dropped from 20,000 ft. Even a slab of this thickness might spall on the under side and drop sizable hunks of concrete.

Sabotage can be prevented by keeping all except operators themselves outside and checking upon the operators. Men who are known to be constantly in debt are legitimate objects of suspicion. In this connection, let me emphasize the importance of having water departments comply with the request of their state water supply coördinator or state department of health to fill out as quickly as possible the form of the Facility Security Program of the U. S. Public Health Service relating to a "Water Supply Security Survey" of certain water departments. This information is most important to the Federal Bureau of Investigation and will be made available to that organization by the U. S. Public Health Service. This survey makes particular reference to the investigation of employees.

Placing of explosives in coal is a simple and very effective way to ruin a boiler plant. If the charge is heavy enough to rupture a part of the boiler, the explosive effect of the released steam may result in complete wreckage of the plant. Lump coal should be carefully examined for camouflaged cans containing explosives. A handful of sand, carborundum, or emery dust in a bearing can cause much damage. For that reason, only persons who are without any doubt entitled to enter should be admitted. An Army uniform should not be accepted unless the wearer can produce a *bona fide* identification card duly authenticated.

The author will say very little about bacterial pollution. The reader probably realizes the absurdity of the idea that a plane can fly

over a reservoir and drop a bag of germs therein and thereby start an epidemic. The maintenance of germs in an active state is not so simple as all that. They can't be loaded like bombs and dropped overboard casually, even if epidemics do start very casually at times. Pollution by bacteria at or close to the gatehouse or other outlet to the reservoir would be disastrous, but pollution at this point from a plane must be deemed nearly impracticable. In any case, a stepping-up of the chlorine treatment would, in most cases, offset such pollution. As to mineral poisoning, for example arsenic in Lewisite gas, the concentration would have to be so great that it is very doubtful that the enemy would attempt to poison a community by dropping Lewisite gas bombs into a reservoir.

The author will leave to the reader's imagination the means by which an engineer and a bacteriologist, working together, could pollute parts of a water supply. No blueprint for doing it will be furnished, but it is one of the things that can only be completely guarded against by the segregation of subversive elements who possess the necessary means, knowledge, engineering skill, bacteria and bacteriological technique. It is simple in principle but difficult of execution.

Damaging of machinery is easily accomplished provided access to it can be had. By access I mean getting close enough to it to throw in a bomb of any sort. The answer is to surround the machinery with a fence, preferably of barbed wire, that will keep the saboteur at a distance from the plant for a long enough time to enable some effective protection to be given. Most machinery is housed. Boarding up windows will help, provided guards are maintained outside the windows. In case of attacks, all running machinery should be stopped at once. Interference will be far less apt to damage quiescent machinery, as running machinery can more easily be caused to damage itself.

Guarding. The primary responsibility for preserving order rests upon the lowest governmental subdivision, which is the city or town. If conditions get out of hand, the municipality may appeal to the Governor to send State Guards. If they are unable to take care of the situation the Governor may request troops from the United States. The primary responsibility for protection of a water supply thus rests upon the owner.

In traveling about and inspecting water supplies, I have found all sorts of guarding, some good and some poor. Generally speaking, a

one-man guard is of very little use, because of the ease with which he can be disposed of. Two men, keeping apart, and generally within sight of each other, are at least four times as effective as one man. Locations removed from settlements should have telephone communication and should call up at designated times, say every hour on the hour. Failure to call should result in an immediate visit from the police; this because of the ease with which a telephone line can be cut. Further, the call should be made in some simple code which is changed every hour. For instance, a girl's name might be used by prearrangement using a different one every hour and *not tacking the list up by the telephone.*

Guards should be armed and properly deputized, if possible, so as to relieve them of civil and criminal responsibility for acts done in the line of duty. Arms should be rifles. Many men have suitable sporting rifles, and the author believes that this type of rifle may still be obtained. The regular Government rifle is not available. The lightest suitable rifle is the Winchester Hornet, which is a 25-calibre rifle with a muzzle velocity 50% higher than that of the Springfield. The smallest pistol that is of any real use is a 38-calibre revolver or automatic.

Fences alone are not sufficient to protect a plant. They serve to make access more difficult than it would otherwise be, and to delay the attackers long enough to enable help to be summoned. You cannot build a fence and then go off and expect it to give you adequate protection all by itself. It may serve to reduce materially the numbers of guards that an unfenced plant would require, but it will not entirely do away with them.

Floodlights should be so placed as to illuminate approaches and not to illuminate either the guards or the places guarded. Care must be taken to see that the floodlighting conforms to dimout regulations.

Guarding is primarily a police function, and owners should guard their property with the means that they have. Using regular police is best, because they are disciplined and because reinforcements can be obtained quickly within the organization.

Certain portions of the Metropolitan District Water Supply of Boston are guarded by federal troops. In this case, in the absence of the help supplied by adequate fencing, which is difficult to obtain, Metropolitan District Police had insufficient personnel adequately to care for these places in addition to their other duties.

In summing up, the author wishes to emphasize that the proper operation of a water supply system is the responsibility of the municipal water department or water company as the case may be. The water consumers pay for the water they consume just as they pay for any other commodity, and they are, therefore, entitled to have their water supply properly protected.

TRAINING AND ORGANIZATION OF TECHNICAL CONSULTANTS TO DEAL WITH CHEMICAL AND BACTERIAL CONTAMINATION

BY LEON A. BRADLEY*

[*Read September 15, 1942.*]

Contaminating Agents. We must not limit our discussion of contamination to a specific chemical substance or even to a related group of chemical agents, such as war gases. We would neglect a most important phase of the problem if the possibilities of biological contamination were not considered. We are not greatly concerned about the probability of massive doses of disease-producing bacteria being used to contaminate water supplies, foods, or land areas directly. (This type of bacterial warfare has been tried by the Japs in China and Burma and the results have not been too satisfactory.) On the other hand, we are keenly aware of a real danger associated with the contamination of food or water by municipal sewage suddenly released from normal channels by the action of high explosive bombs. The reader is too familiar with the network of pipe-line construction under our city pavements to require any further explanation of the "mixing" ability of a properly placed 1000-lb. aerial bomb.

Therefore, the contaminants of greatest importance to civilian defense authorities include certain chemical agents, particularly mustard gas and Lewisite, and the water-borne pathogenic bacteria normally found in municipal sewage.

Value of Contaminating Agents against Civilian Populations. The greatest advantage to be gained by the use of these agents is not casualties or the disruption of industry, but fear and subsequent panic created in the minds of civilians by their threatened use. The effectiveness of war gases or bacterial warfare can be minimized by a program of instruction that informs the public how to recognize the contaminating material, avoid unnecessary exposure, and prevent the careless spread of the contaminating agent. The layman is not well

*Head, Department of Bacteriology, Massachusetts State College, Amherst, Mass.

qualified to carry on such a program because of the very nature of material involved, so it is the duty of civilian defense authorities to train qualified personnel for the supervision of the multitude of problems arising from such contamination.

To carry on a decontamination program effectively, there must also be available the services of technically trained consultants who can provide accurate information to the workers about the nature and effects of contaminating agents. To date, contaminating agents have been used against civilian populations only when a complete lack of protective information has made their use effective—against the Ethiopians and Chinese. Our only immediate defense against this type of warfare is preparedness. Future developments along these lines may determine to a large extent whether or not chemical or biological contaminating agents will be used against our civilian populace.

Duties of the Consultant Corps. Massachusetts is now organizing a technical corps of decontamination consultants with at least one representative in every vital defense area of the state. Professional men and women have received their fundamental training and are now available for consultation service. Their duties have been outlined by Chester L. Churchill, Director of the Technical and Planning Division of the Massachusetts Committee on Public Safety. These duties are:

1. The collection of representative laboratory samples from contaminated materials or areas.

2. Identification of contaminants. The so-called "sniff tests" for the detection and identification of chemical agents may prove inadequate.

3. Determination of the extent of area contaminated and the degree of contamination. Decontamination measures for vesicant agents in vapor and in liquid form present different problems.

4. Acting as consultants to local civilian defense committees concerning decontamination problems—food, clothing, etc.

5. In extreme emergencies, carrying on simple laboratory tests to determine extent and nature of contamination or accurately measuring the effectiveness of decontamination procedures.

6. Serving as ambassadors of accurate public information about contaminating agents.

Training of Decontamination Specialists. Through the vision and

guidance of Arthur T. Weston, Chief Sanitary Engineer of the Massachusetts Department of Public Health, and Chester L. Churchill, Director of the Planning and Technical Division of the Massachusetts Committee on Public Safety, and their associates, a series of four-day schools was organized at Massachusetts State College for the purpose of training a corps of technical advisers to local committees on public safety and civilian defense agencies. Participating in the program were the Massachusetts Department of Public Health, the Massachusetts Committee on Public Safety, Massachusetts State College, and the United States Office of Education.

Through the coöperation of Henry C. Hall, Lt. Colonel, Chemical Warfare Service, and Stanley King, President of Amherst College, facilities of the Army Civilian Protection School were made available to the students, and a portion of the Army's instruction on war gases was made a part of their curriculum. The first of these four-day courses opened on June 15, 1942. They were repeated at two-week intervals, with the fourth course finishing on August 6, 1942.

Qualifications of Candidates. Candidates for these schools made application to the Massachusetts Committee on Public Safety and their qualifications were judged by a committee comprised of Arthur T. Weston, Curtis L. Hilliard, and Chester L. Churchill. A total of 172 men and women (146 men, 26 women) were accepted for the four schools. Certificates of completion have been forwarded to those who satisfactorily completed the course of instruction.

The following data show the professional training of the students, the nature of their present occupation, and their distribution within the state.

Education

Bachelor's Degree	132
Master's Degree	30
Degree of Doctor of Philosophy	16
Degree of Doctor of Medicine	16

Occupation

Municipal employee		45
Health department	22	

Sewage and water department	19	
Engineer	4	
Teacher		38
College	14	
High School	24	
Industrial Chemist		31
State Employee		28
Health department	16	
Institution physician	11	
Institution engineer	1	
Laboratory technician		8
Director of Private Laboratories		4
Practicing Physician		3
Miscellaneous		15

Distribution within the State

Civilian Defense Region I	6
Civilian Defense Region II	35
Civilian Defense Region III	7
Civilian Defense Region IV	28
Civilian Defense Region V	48
Civilian Defense Region VI	12
Civilian Defense Region VII	1
Civilian Defense Region VIII	13
Civilian Defense Region IX	5

Scope of the Training Curriculum. First day: Lectures and Demonstrations—The properties of war gases and methods of civilian protection against these agents; field identification of the gases and demonstration of a new type of decontaminating equipment developed by the Wallace & Tiernan Company of Newark, New Jersey, employing liquid chlorine instead of hypochlorites.

Second and third days: Lectures and laboratory exercises—Methods of detecting bacterial and chemical contamination.

Fourth day: Lectures and Demonstrations—Availability of Chemicals; army methods of decontamination; effect of war gases on food and water supplies.

Plans for the Future. Plans for the organization of a state-wide consultant corps are now nearing completion. Actual supervision of decontamination still remains the duty and responsibility of the various operating divisions of our defense organization. If desirable, they may seek technical advice and assurance from the members of the consultant corps. The state organization will be headed by Arthur D. Weston as Chief of Staff. He will serve as a member of the Headquarters Staff—Technical Corps of the Committee on Public Safety. This group will coördinate decontamination problems with other technical activities such as demolition, shelters, and camouflage. Under supervision of the Chief of Staff each defense region will have its regional officers and local decontamination experts; staff consultants including bacteriologists, chemists, and physicians will study available literature on decontamination and furnish the Consultant Corps with new information about contaminating agents.

The need for such an organization has been recognized by the Office of Civilian Defense, and in July it conducted a "trial school" at the University of Cincinnati. Students were selected from thirteen of the eastern states and received instruction similar to that presented in our Massachusetts courses. In August, courses on decontamination problems were offered at Detroit, Mich.

We believe that in the organization of the consultant corps Massachusetts has again pioneered in a most important phase of Civilian Defense. If preparedness is good protection against the use of contaminating agents, Massachusetts may feel proud that she has fulfilled this obligation.

CHEMICAL CONTAMINATION OF WATER SUPPLIES

BY LAZARUS RUBIN*

[*Read September 16, 1942*]

In attempting to weigh the possibilities of chemical contamination of water supplies under war-time conditions, several factors must be borne in mind. Of first importance is the fact that the so-called "war gases," or chemical agents as they are more correctly termed, have been chosen solely for their effectiveness against personnel when dispersed in the atmosphere. So far as is known, no effort has been made to develop chemical agents primarily for the purpose of contaminating water supplies. As will be pointed out in more detail farther on in this paper, many of these chemical agents are insoluble or only slightly soluble in water. Some undergo hydrolysis, and their toxic properties are reduced and in some cases entirely destroyed when the agent is brought into contact with water. The effectiveness of the various war gases when dispersed into the atmosphere is no measure of their toxicity when added to a water supply.

Another important factor is that of dilution. To illustrate this point, let us assume that we had a moderately large reservoir of, say, 100-m.g. capacity; further that it was desired to render this water unfit to drink by the addition of 100 p.p.m. of a soluble, toxic substance. Such dosage would require the addition of 83,000 lb. of this agent well distributed to render this water unsafe to drink. From these figures it can be seen that in the case of large reservoirs the possibilities of chemical contamination are slight except where this contamination takes place in the immediate vicinity of the gatehouse or intake pipe. Where there is a gas attack from the air and several gas bombs are dropped into one end of a reservoir, the concentration of the agent may reach several times the lethal dose at this point. However, it may well be that the concentration at the intake may never reach harmful proportions if the intake is far enough away from

*Senior Chemist, Water and Sewage Laboratories, Massachusetts Department of Public Health, Boston, Mass.

the point of attack and the reservoir is large. In small reservoirs of from 0.1-m.g. to 1.0-m.g. capacity, the margin of safety due to dilution is less. However, for gas attack from the air the possibility of a direct hit on such a small body of water is correspondingly less.

Many of the chemical agents, if present in a water supply, can be satisfactorily removed by coagulation, sedimentation, filtration, chlorination, and carbon treatment. Therefore, municipalities having water treatment plants have additional protection against possible attack by the war gases.

As to the possibilities of sabotage by chemical means, effective sabotage is possible, especially on small bodies of water. The best protection against this form of attack is vigilant guarding of reservoirs and patrolling of watershed areas. While it is not for the chemist to pose as an expert in military matters it would seem, in view of the data already mentioned, that, especially in the case of organized sabotage, for the same expenditure of effort more effective disruption of the water system can be accomplished by other means such as the use of high explosives.

Let us consider the various agents in chemical warfare and determine the effect of their presence in a water supply and the possibilities of decontamination. When an area has been subjected to gas attack any open body of water such as a pond, lake, or stream in the vicinity may be contaminated either by direct hit or by absorption of vapors from the surrounding atmosphere. Ground water supplies are relatively safe from this form of contamination.

The chemical agents may be classified according to their physiological effects as lung injurants, vesicants, lacrimators, irritant smokes, screening smokes, and incendaries.

Lung Injurants

These agents are non-persistent gases; that is, effective concentrations of their vapors at the point of release do not last more than 10 minutes.

Chlorine. Chlorine is a gas quite soluble in water. Its presence in excessive amounts in a reservoir would result in the development of disagreeable tastes and odors. However, if the water is at all palatable there will be no harmful effect on health through its use.

Where necessary, dechlorination may be carried out at the source by the use of sulphur dioxide gas, sodium sulphite or sodium thiosulphate. It may also be carried out by the consumer by heating the water to remove the excess gas. In any case, some residual taste will remain.

Phosgene. Phosgene is a gas at ordinary temperature and liquefies at 8°C. to a liquid usually pale yellow in color. Its vapor is 3½ times as heavy as air. On contact with water it hydrolyzes almost immediately into hydrochloric acid and carbon dioxide, both of which are relatively harmless to health. Under most circumstances this would result in the rapid disappearance of phosgene from the water. However, the unpleasant taste would probably disappear less rapidly. Aeration of the water supply and the addition of activated carbon, where facilities are available, will speed this process. The addition of either lime or soda ash will also aid in the removal of phosgene and in the adjustment of the pH of the water supply.

Diphosgene. Diphosgene is a liquid boiling at 120°C. Like phosgene, it hydrolyzes, but much more slowly, in contact with water and forms hydrochloric acid and carbon dioxide. As in the case of phosgene, the presence of this agent in any concentration will only result in some change in the pH of the water supply and possibly in the development of unpleasant tastes and odors. The presence of either of these gases in a water supply will not render the supply harmful to health except possibly when they are present in marked concentrations or when they are used in solution with an organic solvent. The addition of lime, soda ash, and carbon will help in the decompositon and removal of these agents.

Chlorpicrin. This substance is a slightly oily, colorless liquid having a boiling point of 112°C. It is soluble in water to the extent of about 1,700 p.p.m. and fairly stable even in boiling water. Chlorpicrin imparts to water an unpleasant odor and extremely harmful physiological properties. Its odor can be detected when the substance is present in concentrations as low as 5 to 10 p.p.m. It has been suggested that the waters containing more than 20 p.p.m. of this chemical agent should be considered non-potable. However, there are practically no data available as to the physiological effects of small amounts of chlorpicrin in a water supply. The removal of this substance offers

a real problem. Where facilities for aeration and the addition of large doses of activated carbon are available, some success may be had with its removal. Under ordinary circumstances, however, where the presence of this substance in a reservoir has been established, especially where its odor is perceptible, the body of water should be abandoned for domestic use.

Vesicants

Mustard gas and Lewisite are both persistent vesicant agents. They produce casualties by contact with the exterior or interior portions of the body. They volatilize rather slowly, and effective concentrations may remain at the point of release for days and weeks.

Mustard Gas. Mustard gas is an oily liquid, colorless when pure but brown in the crude product, with a melting point of 14.4°C. and a specific gravity of 1.27 at 20°C. It has a pungent odor that has been described as similar to mustard or garlic or horseradish. Its vapor is 5½ times as heavy as air. Mustard gas is soluble in water to the extent of about 700 p.p.m. It undergoes hydrolysis in cold water and much more rapidly in boiling water. At ordinary temperatures, 50 per cent of the amount of mustard gas in solution undergoes hydrolysis in 10 minutes, and 85 per cent in 60 minutes. The product of hydrolysis is thiodiglycol, a colorless, syrupy liquid soluble in water, in ethyl alcohol, acetone and chloroform, and sparingly soluble in ether, benzene and carbon tetrachloride. This substance has no vesicant properties and is relatively harmless to health.

The effects of small amounts of mustard gas dissolved in water on the human system are not well known. Therefore, where other supplies are available, the safest procedure when a reservoir has been exposed to attack by mustard gas is immediately to abandon the use of the supply, regardless of the concentration of mustard gas in the water. Some recent work indicates that if the concentration is less than 500 p.p.m. it may be feasible to decontaminate the supply by the addition of large doses of activated carbon followed by coagulation, sedimentation and filtration, and chlorination beyond the break point, i.e., 10 to 50 p.p.m. Whenever possible, an emergency intake should be arranged as far from the location of the mustard bomb as possible and as near the surface as feasible. Ruchhoft and Schott

have suggested as a criterion of potability that the filtered water have a 5-minute chlorine demand of less than 5 p.p.m.; otherwise additional chlorination must be undertaken. It can be seen that a water so treated would be quite unpalatable, even if not harmful to health. Water containing small concentrations of mustard gas can be decontaminated by boiling it in a pressure cooker for 30 minutes to an hour. However, all procedures for decontamination are rather hazardous and should not be resorted to unless no other water supply is available.

Lewisite. Lewisite is a colorless liquid when pure, but the commercial product is dark in color. It has a specific gravity of 1.89 at 20°C. and a boiling point of 190°C. It has a very characteristic odor of geraniums that can be detected even in great dilutions. In water, Lewisite undergoes very rapid hydrolysis to chlorvinylarsenious oxide which is a white, crystalline solid, sparingly soluble in water, alcohol and carbon disulphide. This oxide also has vesicant properties.

As in the case of mustard gas, the physiological effects of small amounts of Lewisite dissolved in water have not been definitely established. However, Lewisite is an arsenical poison. Recent discussions relative to new U. S. Treasury Standards indicate that a potable water supply should contain not more than 0.1 p.p.m. of arsenic in solution. These standards apply to water in continuous use. Under emergency conditions, water supplies having a considerably higher arsenic content, possibly 10 to 20 times as high, can probably be used for very short intervals without any deleterious effect on health. Such supplies, however, should be used only under strict technical supervision, and prolonged use of these supplies should be avoided.

Some work has been done on the removal of Lewisite and other arsenical compounds by the use of iron salts followed by coagulation, sedimentation, and filtration. As yet, only few data on this problem have been made available. In any case, where a water supply is so treated, the arsenic content of the final effluent should fall within the limits previously mentioned.

Lacrimators

Lacrimators may act either as persistent or non-persistent agents depending upon their mode of discharge. They cause intense irritation of the eyes, producing a flow of tears.

Chloracetophenone. This substance is a solid melting at 58°C. It is soluble in water to the extent of about 1,000 p.p.m. and is not hydrolyzed even by boiling water. It is ordinarily dissolved in other gases or organic solvents and dispersed through the air as finely divided particles or melted with magnesium oxide and mixed with nitrocellulose in the form of irritant candles. Due to its mode of dispersal it is extremely unlikely that enough of this chemical agent could reach a water supply to cause any serious contamination. Little is known regarding the physiological effects of the presence of this substance in water.

Brombenzylcyanide. Pure brombenzylcyanide is a solid melting at 25°C., although the technical product is an oily, brown liquid due to the presence of impurities. It is almost insoluble in water and only slowly decomposed by it. This lacrimator is, however, soluble in most organic solvents and in several of the war gases, such as phosgene and chlorpicrin, and is often used together with these gases for a wider range of effects. The presence of this persistent lacrimator will impart a very unpleasant odor to water. While it is difficult to say what the effects of small amounts of this substance in water would be, the fact that it is often used in conjunction with other war gases, especially mustard gas, should be sufficient reason to cause the temporary abandonment of a water supply that has been exposed to considerable concentrations of its vapors.

Irritant Smokes

Due to their mode of dispersal as finely divided particulate clouds, these agents are classed as non-persistent. They produce irritation of the nose, throat and eyes.

Diphenylchlorarsine (*Sneeze Gas*). This substance is a solid that is usually discharged into the air in a very fine suspension either by explosion or by evaporation of solvents. It is soluble in water to the extent of about 1,000 p.p.m. and undergoes slow hydrolysis to the corresponding oxide. The latter is also an arsenical compound slightly

soluble in water. The presence of considerable quantities of this substance in a reservoir would produce a turbidity in the water that could be removed where facilities for coagulation and filtration are available. The arsenic content, however, should be carefully determined before allowing contaminated water to enter the distribution system.

Adamsite (*Diphenylaminechlorarsine*). This substance is a solid at ordinary temperatures. It is sparingly soluble in water and undergoes very slow hydrolysis to the corresponding oxide. Its effect on water supplies and the treatment of such supplies is the same as that of sneeze gas.

Diphenylcyanarsine. This substance is similar in properties and reactions to Adamsite and sneeze gas.

Screening Smokes

Screening Smokes. The use of smokes involves little hazard to water supplies. Where a water supply has been exposed to these agents in considerable concentration, tests may be made for the presence of phosphates, sulphates, tin and titanium. However, it is unlikely that harmful concentrations of any of these substances will be absorbed by a water supply, although the taste may be affected; also, there may be some change in the pH of such a supply which can easily be adjusted by the use of lime or soda ash. The only one of these agents that offers any danger at all is undecomposed phosphorus in suspended particles. This substance is a white solid that undergoes decomposition when exposed to the atmosphere. While the smoke does not affect water supplies, any solid particles of the undecomposed phosphorus are poisonous. Where facilities for filtration are available, any such suspended matter may be removed.

A great deal of work has been done on the development of rapid, simple chemical tests for the presence of the various war gases. Since most of the gases on hydrolysis yield acid solutions, the change in pH of a water supply is an indication of the presence of one of the war gases; also, since many of them contain chlorine atoms, a marked increase in the chloride content is another indication of the presence of a chemical agent. Similarly, the oxygen consumed determination, the chlorine demand, and the alkalinity can be used as rapid, simple tests to indicate the presence of a chemical agent.

Odor and Appearance. The odor of mustard gas when present in water can be detected in concentrations as low as 10 p.p.m. The odor of chlorpicrin is perceptible in concentrations as low as 5 to 10 p.p.m. Almost all of the chemical agents have a distinctive odor which may be classified as follows:

Odor Imparted to Water by Various Chemical Agents

Chemical Agent Present	*Odor of Sample of Water*
Chlorine	Chlorinous, like bleach solution
*Phosgene	Musty, acrid, like ensilage
Chlorpicrin	Sweetish, like licorice or flypaper
Mustard gas	Like mustard, garlic or horseradish
*Lewisite	Like geraniums
Chloracetophenone	
Brombenzylcyanide	Unpleasant, like sour fruit
Adamsite	Smoky
Diphenylchlorarsine	Like shoe polish

*Hydrolyzes rapidly in water. Odor may be rapidly dissipated.

It must be noted that while the descriptions of the odors are intended to be accurate, the perception of odor is extremely variable in individuals and it is necessary to have some experience with the various chemical agents to become acquainted with the odors involved. It must also be pointed out that it was common practice during the last war to use mixtures of two or more gases both for deception and for a wider range of effect. For instance, chlorpicrin, on account of its marked odor and its ability to dissolve some other war gases, was used in combination with other war gases, such as phosgene. The use of tear gas, such as brombenzylcyanide, was often followed by mustard gas. Considerable work has been done on producing odorless mustard gas and odorless Lewisite.

Most war gases are heavier than water and if dropped into water will sink to the bottom; but some, like mustard gas, will leave an oily film on the surface which may remain visible for from 24 to 48 hours. Lewisite forms a white, insoluble powder. Suspended particles may be chloracetophenone, Adamsite or diphenylchlorarsine.

Hydrogen Ion Concentration. A lowering of the pH is an indication of the presence of an acid product of hydrolysis. Mustard gas, Lewisite, phosgene, diphosgene, ethyldichlorarsine and diphenylchlorarsine all give this reaction in water. In Metropolitan-Boston tap water, for instance, 5 p.p.m. of mustard gas in contact for one hour changed

the pH from 6.7 to 6.5 and 20 p.p.m. changed the pH from 6.7 to 5.8.

Chlorides. Tests have shown that 5 p.p.m. of mustard gas in contact with water for one hour increased the chloride content by 2 p.p.m., and 20 p.p.m. of mustard gas raised the chloride content by 6 p.p.m.

Chlorine Demand. Since a large number of the chemical agents react quite readily with free chlorine, the chlorine demand of a water supply can be used as an indication of the presence of such agents. For instance, Ruchhoft and Schott report the chlorine demand of a tap water with 500 p.p.m. of mustard gas was 513 p.p.m.; with 500 p.p.m. of Lewisite, this demand was 213 p.p.m.

All of these determinations are of value in indicating the presence of a chemical agent in a water supply in an area that has been subjected to gas attack. They are especially useful where only non-technical personnel is available for making such tests. In this connection it would be advisable to make routine determinations of pH, alkalinity, chlorides, oxygen consumed and chlorine demand periodically and that necessary base data be made available for possible use during an emergency. However, these determinations do not help in identifying the particular agent present nor in determining very exactly its concentration. They merely indicate the presence of some chemical compound.

While several accurate tests are available for the detection of each of the chemical agents, tests for only two of these, namely, mustard gas and Lewisite will be discussed here. From a study of the various chemical agents available and their toxic properties, it seems quite certain that these are the gases most effective in attack and the ones most likely to be used.

It must be pointed out that in testing water supplies suspected of contamination with one of the war gases, several precautions must be used. Since the substances in solution or in suspension in the water sample may have harmful physiological effects, if brought into contact with the skin or with mucous membranes, care should be taken to wear rubber gloves or gloves treated with some substance such as "impregnite." In addition, the sample should never be poured from the original container into a flask or graduate but should be siphoned out. All work should be carried out under a hood or at least in a well-

ventilated room. Boiling or heating the sample should be avoided as much as possible, as the vapors arising from the sample may be poisonous. All apparatus used must be decontaminated after the analytical work has been completed. For this purpose, where mustard gas is being tested for, concentrated nitric or chromic acid is most suitable for glassware, while rubber tubing and metal should be boiled for 30 minutes in water. Where Lewisite or other arsenical gases have been tested for, washing with 20 per cent sodium hydroxide followed by water and chromic acid is satisfactory. For most other war gases, washing with hot alcoholic sodium hydroxide should be used. Where the presence of chlorpicrin has been suspected, a hot aqueous alcoholic solution of sodium sulphite (3 per cent sodium sulphite) can be used.

Detection of Mustard Gas in Water. Mustard gas is an organic sulphide and a powerful reducing agent. The following test is based on its ability to reduce an acid solution of selenium dioxide and is an adaptation of a method used in the last war.

Siphon 100 ml. of the water sample into a separatory funnel and add 50 ml. of ethyl ether. Extract and discard the water layer into a stoppered glass bottle. Repeat the extraction with another 100 ml. portion of the sample, using the same ether solution. Between 100 and 1,000 ml. in all should be extracted with the same portion of ether, depending upon the extent of the contamination as determined from field data and preliminary examination of the sample. Care must be taken that there be no spattering of either the sample or the ether solvent. It is necessary between shakings to invert the separatory funnel and open the stopcock to relieve the pressure and vent any fumes into a hood. The ether layer is then drawn off into a 250-ml. Erlenmeyer flask or into a 100-ml. wide-mouth Pyrex flask of the type used for fat extraction. The flask is stoppered with a two-hole stopper fitted with two glass tubes, one of which projects into the flask just above the surface of the ether layer. The flask is warmed gently on a water-bath under a hood, and the evaporation of the ether is facilitated by a gentle stream of air over the ether layer. The exhaust vapors are bubbled into a strong solution of bleach (5 to 10 per cent available chlorine).

When the ether has boiled down, connect the glass tube which has been in the bleach solution, after first thoroughly washing the tube, to a test tube containing from 10 to 20 ml. of selenium dioxide dissolved in sulphuric acid. This solution is prepared by dissolving 1 gram of selenium dioxide in 100 ml. of a 1:1 solution of sulphuric acid. The test tube should be fitted with a two-hole stopper equipped with two right-angle glass tubes, one of which should dip into the liquid; the other should be connected to a bottle of strong bleach solution.

The flask containing the ether extract should be warmed gently on a water-bath in a stream of air and the vapors should be bubbled through the selenium dioxide solution. After 10 to 20 minutes, the test tube containing the selenium dioxide should be removed from the apparatus and heated on a water-bath at 85°C. (+ or — 5°) for 10 minutes and then cooled to room temperature.

The presence of a salmon-colored turbidity or orange precipitate indicates the presence of mustard gas; as little as 0.005 mg. can give a turbidity. This test is not specific as it is given by all arsine derivatives, carbon monoxide, and hydrogen sulphide.

In place of selenium dioxide solution, as described, a 0.1 per cent aqueous solution of gold chloride will give a yellowish turbidity with mustard gas. This test is as sensitive as the selenium dioxide test.

Detection of Lewisite and other Arsenical Gases in Water. Since Lewisite as well as several of the sneeze gases are arsenical compounds that hydrolyze in water, they can be detected most readily by the use of a test for arsenic. A very satisfactory test is the Gutzeit test. This can be either qualitative or quantitative.

Soak strips of heavy, close-texture filter paper, similar to Whatman's No. 40, for one hour or longer in a freshly prepared 5 per cent mercuric bromide solution in alcohol. Remove from the solution and dry on glass rods. Cut strips exactly 2.5 mm. wide and 12 cm. long. Prepare a gas generator consisting of an 8-oz. wide-mouth bottle fitted with a one-hole rubber stopper. Into this hole insert a glass tube 1 cm. in diameter and 6 to 7 cm. long constricted at one end. Fit a one-hole rubber stopper into this tube and insert in this stopper a narrow glass tube 2.6 to 2.7 mm. in diameter and 10 to 12 cm. long. Place a small wad of glass wool moistened with 10 per cent lead acetate solution in the constricted bottom end of the wider glass tube. After connecting the narrow tube by means of the rubber stopper, insert a strip of mercuric bromide paper into this tube. Handle only one end of the strip when inserting.

Siphon into the bottle 100 ml. of the sample and add 5 ml. of concentrated hydrochloric acid and then add 5 ml. of a 15 per cent potassium iodide solution and 4 drops of a 40 per cent stannous chloride solution in hydrochloric acid. Add 5 grams of granulated zinc, free from arsenic, and allow the evolution of gas to continue for 1½ hours. It is best to keep the apparatus at a constant temperature. A yellow or brownish stain on the paper indicates the presence of arsenic. The length of the stain is proportional to the amount of arsenic present. A blank should be run using distilled water or uncontaminated water and the same amount of the various reagents. In order to make the determination quantitative, samples containing known amounts of arsenic are run in the apparatus under the same conditions. This test is quite specific for arsenic. Quantities of arsenic as low as 0.001 mg. as As_2O_3 can be detected in this way.

This report is intended as a summary of our knowledge on this subject at the present time. It is hoped that further data will be obtained and made available shortly.

REFERENCES

Mario Sartori. The War Gases. (Translated from the 2nd Italian Edition by Morrison). D. Van Nostrand Co., Inc. New York, 1939.

A. M. Prentiss. Chemicals in War. McGraw-Hill, New York, 1937.

Kurt Wachtel. Chemical Warfare. Chemical Publishing Co., Brooklyn (1st American Edition), 1940.

British Home Office. The Detection and Identification of War Gases.

Manual. Course on Chemical Decontamination Problems. Sponsored by Massachusetts State College, Massachusetts Department of Public Health, and Massachusetts Committee on Public Safety.

Technical Manual for the Senior Gas Officer of Civilian Defense. Prepared under the Direction of the Medical Division of the Office of Civilian Defense and the National Institute of Health, Division of Public Health Methods, Cincinnati, Ohio, July, 1942.

INSTRUCTION IN WATER BACTERIOLOGY AT THE MASSACHUSETTS DECONTAMINATION SCHOOL

BY JOSEPH A. McCARTHY*

[*Read September 16, 1942.*]

It was not our intention, in conducting the bacteriological work at the Massachusetts Decontamination School, to make finished bacteriologists in the few days at our disposal. Our plans were to give instruction in the collection of bacterial samples and to explain the preparation of satisfactory sampling bottles in an emergency, the possibilities of contamination of our water supplies—not only by enemy action but also by storms and accidents, the effectiveness of chlorine treatment, a small amount of laboratory work following standard methods for the examination of water, and finally an emergency method for the presumptive test for coliform bacteria.

Samples. The course included a comprehensive study of methods of collecting representative bacterial samples, with an attempt to explain the reasons for all the precautions that must be taken; and this of course included stressing the necessity for making as short as possible the interval between collection and analysis. Considerable emphasis was placed on the proper identification of samples, each student was urged to observe and record all the information possible regarding each sample, and it was attempted to bring home to each one how important such details might become. Following this lecture work, field trips were made, and each student was asked to collect a sample from a running stream and from a pond. In each case classroom instruction was repeated in the field with illustrations there available, especially in regard to information about the samples.

On returning from the field trip, each class was given a discussion on the taking of tap samples, and actual samples were then collected from taps. Further information was given regarding the drawing of samples from wells, tanks, water carts and other possible miscellaneous sources. Practically all of this work was done with an emer-

*Chief of Laboratory, Lawrence Experiment Station, Massachusetts Department of Public Health, Lawrence, Mass.

gency bacterial sample bottle that was chosen for the course. The container was an ordinary 8-oz. druggist's prescription bottle with the measurements shown on the side. This type was selected, because we found it to be available in reasonable quantities in practically every drug store throughout the state and generally purchasable in large quantities in any city or town big enough to support a wholesale drug establishment. The bottles were cheap and withstood sterilization very well. For the plug necessary for the bacterial sample bottle, we used nonabsorbent cotton rolled in gauze and then enclosed in ordinary cellophane. We found, under actual field conditions, that this composite plug stood up well under sterilization and made the bottle proof against contamination and likewise waterproof except, perhaps, under extreme conditions. Instructions were given the classes regarding the necessary sterilization of such bottles and the various possible ways of obtaining satisfactory sterilization in emergencies, either by dry heat or pressure cooking.

Possibilities of Contamination. A model village was set up in the laboratory. The model included a reservoir, treatment plant, pumping station and distribution mains as well as sewers leading to a sewage treatment plant. By means of a small pump and motor, it was possible to circulate the water in this village. Several streets were laid out on the surface of the model, and various buildings were distributed over the surface. At one site we had an imaginary incident in which the street had been so torn up that both water mains and sewers were broken. The classes were given numerous examples of actual breaks experienced during the New England flood of 1936 and the hurricane of 1938, and some of the effects of these breaks were described. Various sites were then selected in the model village, including one sample site above the scene of disaster, one immediately below the break, and two sites at which it might be uncertain, under actual conditions of operation from just what part of the water distribution system the water in the mains at that time had come. Samples were then collected by each member of the class individually from some of the sites as a further check on their sampling technique, and other samples were prepared in advance and given to the class for analysis. On the following day, when the results of the 24-hour bacterial examination were available to the class, an attempt was made to further

impress upon the class the number of samples necessary should such an incident happen to a water supply, the great distance over which water supplies may become contaminated by such occurrences, and the possibilities of uneven distribution of the contaminating sewage in the mains. Likewise, each class was taught to think about the necessity for further sampling on subsequent days since flushing and other emergency methods might not have succeeded in entirely clearing the system of contamination. The class was also given a brief sketch of the means employed in repairing damage, including pumping out of the crater, thorough chlorination of the pipe before replacing it in the trench, and chlorination of the whole system when repairs have been completed, as well as flushing, and all the other precautions that might be necesary.

Effectiveness of Chlorine Treatment. Among the samples distributed to each student were two bottles of water absolutely identical in appearance and indistinguishable except by bacterial analysis. One of these samples represented a possible emergency supply before chlorination and the other the same supply after proper chlorine treatment. Each member of the class made his own analysis and on examination of the results must have been impressed by the difference between these two otherwise indistinguishable samples. This part of the course was correlated with the work in the chemical part of the course in which the students were given instruction in ortho-tolidin tests, etc.

Bacterial Work. The actual bacterial work began with a general lecture on bacteria and the role they play in the world, and this led up to a discussion of water-borne pathogens and then to the coliform bacteria and why they are used in the determination of sewage contamination of water. Then each student was given a slide for microscopic examination showing three types of bacteria and a budding yeast. This gave students with no previous microscopic experience at least an idea of the appearance and size of the organisms they were to study. The methods and the precautions necessary for the preparation of bacterial media from dehydrated broth were next demonstrated, and then each student individually made a small portion of lactose broth from the dehydrated material. Later on in the course, he was given instruction on the availability of material for such

media; our own investigation before the course started showed that in case of extreme emergency it will be practically always possible to obtain the necessary ingredients even if all our stocks of bacterial media have been destroyed. Demonstrations were then given of the technique of the presumptive test for coliform bacteria in water supplies, and following this instruction each pupil, under supervision, was asked to actually set up three distinct samples for the presumptive test.

Following this work on Standard Methods, the students were also given instruction on an emergency presumptive test for coliform bacteria which has been developed at the Lawrence Experiment Station. We have, in the past year, done a considerable amount of work, in connection with the proposed revision of standard methods, on sample portions of 50 and 100 ml. In the course of this work, it was demonstrated that practically none of the existing Massachusetts water supplies will show a positive presumptive test in 50 ml. portions in 24 hours. This finding was made the basis for the emergency test that was used in the Decontamination School. The emergency sample bottle was used as a fermentation tube and 10 ml. of lactose broth, made five times the normal strength, was added to the bottle. The concentrated broth was the medium prepared by each student. Consequently each student was able to carry on the emergency tests with bacterial media that he himself had made. A very high degree of correlation between this emergency test and the five individual 10-ml. portions, according to Standard Methods, was found in the work at Amherst. On a total of 147 tap samples examined in parallel by the students, the Most Probable Number of coliforms per 100 ml. calculated according to the formula of Dr. Thomas* was 0.192 when 10 ml. portions were used, 0.231 when 50 ml. portions were substituted, and 0.211 for the combined results. This indicates that this emergency method, even in the hands of comparatively untrained personnel, can give results comparable to those obtained by ordinary methods.

At the present time the Committee on Public Safety is planning an emergency kit that will consist of five of the emergency sample bottles, one of which will contain 100 ml. of strong lactose broth. As

*Jour. Am. Water Works Assn., 34, (1942), 572.

the bottles are calibrated on the side it will be possible, by using this kit, to dispense entirely with pipettes. All that will be necessary will be to take 50 ml. of sample, pour in 10 ml. of the already prepared media, and then proceed to incubate under the best conditions possible. The various types of emergency incubators were discussed during the course and, once the interest of the groups had been aroused, a number of very valuable suggestions were presented by members of the class.

As the work was based primarily on the fact that Massachusetts water supplies do not show positive presumptive tests in 25 hours in 50 ml., it was considered unnecessary for the class to learn the further steps of confirmation and completion of the coliform test. However, these steps were demonstrated to the class and sources for further study were given to those who might desire later on to take this up.

Under general instructions, the classes were given descriptions of the present method of coverage of all the water supplies of the state by means of mailed bacterial samples, and each one was urged, when he returned to his own community, to become acquainted with the sample collectors in his own city or town. The classes were also told of the present emergency set-up of replacement laboratories that makes it rather improbable that it will ever be necessary for them to resort to the emergency methods that were taught at the School.

The possibility of deliberate contamination of water supplies was likewise discussed, and the classes were shown the ordinary safeguards as well as the emergency methods now in use against the possibility of such contamination becoming dangerous over a widespread area. The classes were constantly impressed during the course of the lectures that our emergency methods were not intended in any way to supplant the regular work of state and city laboratories nor was there any intention, except under extreme conditions, of giving up Standard Methods. However, we feel that while it is very unlikely that all our laboratories might be put out of existence it has been our experience in the past that it is extremely difficult to get enough trained sample collectors to collect the vast number of samples necessary if, for example, we had a repetition of the 1936 flood. Consequently we feel that the instruction of almost 200 technical men and

women in the proper technique and proper identification of samples, together with suggestions for the preparation of emergency sampling bottles, if it became impossible for the regular laboratories to supply them, in itself is a justification for the work of the course. We think it is further important that most of these 200 citizens have been led by this course to think about the importance and the value of their home water supply.

It was gratifying to a citizen of Massachusetts to find the laboratories of our State College equipped to accommodate our large classes, and it is a pleasure to express our appreciation for the coöperation of the authorities at the College, particularly to Dr. Bradley and his associates in the Department of Bacteriology.

THE WAR DEPARTMENT CIVILIAN PROTECTION SCHOOL AT AMHERST COLLEGE, AMHERST, MASS.

ADDRESS BY HENRY C. HALL*

[*Read September 15, 1942.*]

There is one thing that we can agree on, and that is that water is one essential without a substitute, in war as in peace. You need not expect any learned discussions from me about your responsibilities in wartime. I am going to take a little time to tell you about the WDCPS. Not many of you have heard about that, I imagine, but that stands for War Department Civilian Protection School, and they are running one out at Amherst. We have already had thirteen matriculations there since the 23rd of March, have had twelve senior banquets and twelve commencements, and there is to be another senior banquet tomorrow and another commencement. Next Sunday we will have our fourteenth matriculation. The enrollment for the fourteenth class will be limited to those persons who have responsible charge of industrial plant protection. This is the first specialist school that we have run. All of the other thirteen schools have been general schools, open to anyone who could stand up under the investigation of the FBI, have his fingerprints taken, be cleared by his State Chairman, or his War Council or any member of the Committee of Public Safety, and then be cleared by the Regional Director of the National Defense Region. That school serves both the first and the second regions, which are the same as the first and second corps areas, now the first and second service commands. Anyone from those regions can come if he is properly cleared. Seven hours are spent on aerial attack, four hours on civilian protection organization, thirteen hours on gas protection, nine hours on incendiary protection, four hours on plant protection, four hours on local training, fourteen hours on citizens protection corps, ten hours on general subjects, or a total of sixty-five hours on hard chairs. We do that in nine and one-half days and then we have another graduation.

There is not any tuition for this school, but the day you register

*Lt. Colonel, Chemical Warfare Service, Director.

you pay $25, which is for your quarters and your mess for those ten days. The students live at the Lord Jeffery at Amherst, in style. They eat at the Valentine Dining Hall, and I want to say to the credit of Amherst that we have never eaten so many consecutive meals that have been so consistently well prepared, well cooked, and show the quality of purchasing that Amherst College does for the men who eat at the Valentine Dining Hall.

You may wonder why it is necessary to have a War Department Civilian Protection School. I would like to say to you right now, before we go any further, that you are all in this war. It is a different kind of war than the world has ever seen before, and everybody is in it. That is the why of the War Department Civilian Protection School.

When the OCD was first set up they said, "We need military instructors." The War Department said, "Oh, my, no; no, that has never been heard of before; the civilians attend to their business, and the Army is of a very exclusive type, we can't mix them up." But the OCD insisted, and I imagine that the general staff, after lengthy and intricate conferences, finally yielded and said, "O.K.; you probably want to know something about incendiaries, you want to know something about gas, so that we will make that instruction the responsibility of the Chemical Warfare Service." So that in July, 1941, they established a school at Edgewood Arsenal, and people came there from all over the United States, but the people who came were largely firemen and policemen, all on the city payrolls. That school ran for sixteen classes, and along in the fall they saw the idea was going to take, and they made some plans for extending the school. Those plans were moving along in the usual military fashion in time of peace when Pearl Harbor came, and then the plans went into double time. It was not long after that, before they opened a War Department Civilian Protection School on the campus at Stanford University, another in Texas, another at Amherst College. A fourth was created by moving all the civilian instruction out of Edgewood Arsenal over to the University of Maryland. They have another one down at the University of Florida, another at Purdue University, another at Washington University, and another is opening next week at Occidental College at Los Angeles.

There are now about seven hundred people a month, being trained

in all the subjects of civilian defense;—people trained to go out and to organize and instruct instructors, so that when the time comes the home front will be able to carry its end of this load, of this fight, this scrap, of which every one of us is a part. So that is the why of Civilian Protection so far as we see it today.

It might be well to digress for just a moment or two. We learn that one of the major problems of either side in any war is the protection of the concentrations of noncombatants. If we go clear back to the cave man we find that, when he went out to fight, the end of the battle was victory or death, and he was fighting to protect his cave and his family. Then history tells us that those cave men learned a few things, they learned about different kinds of weapons. They learned to throw a rock in a sling. As those weapons were introduced, the distance between the combatants began to lengthen; they were no longer toe to toe and breast to breast. The bow and arrow and the longbow had ranges of 200 yards. And as the distance between the combatants was stretched out, as they fought farther and farther apart, the problem of the protection of the concentrations of noncombatants became greater and called for more organization. Soon we find the combatants grouping themselves into tribes and organizing into armies, and we find that the organization for the protection of civilians and noncombatants required the building of walls and moats. Then in the thirteenth century, when the Germans used gun powder, was the first time for military purposes that there was introduced the forerunner of our present howitzer.

Every time the weapons of warfare were improved, the distance between the combatants increased, and as that distance increased there was an increased necessity for the protection of concentrations of noncombtants. We can see that today. The protection of concentrations of noncombatants is one of the major objectives of every army. We saw it in our Civil War, when they fought for four years, the army of the Potomac doing its best to attack Richmond, the Confederate army attempting to reach Washington, and when Richmond was open to attack and could no longer be defended they surrendered at Appomattox. That thing very nearly happened in the first battle of the Marne; they almost got through to Paris, but by shrewd strategy the thing turned, and it was the turning point of the World War. When

the German high command learned that Berlin could no longer be defended they asked for an armistice and got it.

We have seen it in this war, at Prague, Warsaw, and Paris. When those concentrations of noncombatants could no longer be defended that side fell. We saw it at London, but the attack on London was not a success. For some reason, which we will be talking about for years, it did not succeed. So it happened that when Moscow was threatened they moved to the west, clear over to Kuibishev, showing that the major objective of either side is the protection of the civilians, the safeguarding of the homes and lives of the families of the warriors, the safeguarding of the seat of government, the heads of the government, and the protection without interruption of the manufacture of the sinews of war.

So it is today in our country. The major objective of our armed forces is the protection of the concentration of noncombatants. That is the why of the War Department Civilian Protection School, because today the distance between the fighters has been stretched out to where a plane can make a one-way, non-stop trip, the best ones, of seven thousand miles, where the speeds are up as high as four hundred miles an hour and maybe higher now. I don't know about that, as much of that is a military secret and we can't find out about it. So it is that as the distance grows between the combatants, it leaves the noncombatants, the civilians, where? Right squarely in the middle.

That is why, gentlemen, you are all in this war, whether you have a khaki suit on or not. That is why every man, woman and child in our country today is going to feel the impact of this war. They are going to feel it in many different ways. Some of the ways we have already. Our income taxes have been increased; we have been up against a little rationing, but not nearly as much as we are going to know about; we have had to buy some war bonds, and are going to have to buy a lot more. Selective service has reached into some of our homes, but it is going to reach into a lot more of them, it is going to reach down every street of every hamlet, village and town of this country, directly or indirectly.

Then we are going to have another reminder that we are in this war, and that is going to be the casualty lists. We can't be in a war such as this without paying a big price in materials, in munitions, and

we are going to pay in blood. Those casualty lists are going, directly or indirectly, to affect every one in our country.

I just want to remind you that two hundred and eighty-one times the sun has set, and two hundred and eighty-two times the sun has risen since our country went to war, and we are going to have to have some coöperation of the organized groups, we are going to have some team play, if we are going to carry this battle over that goal line which we think we can see.

I wonder how many of you knew Tiny Maxwell. He was quite prominent in intercollegiate football, as an official in recent years. Tiny weighed about three hundred, and stuttered. He was coaching a team in a little college in southern Pennsylvania, and he had a very dear friend in New York who never failed to be there when Tiny's team was playing if he could possibly get away from New York. This Saturday afternoon he got there between the halves and he didn't know that the score was 52 to 0 against Tiny. He rushed into the locker room and said, "Well, Tiny, how are things going?" Tiny said, "N-n-not so g-g-good on the d-d-defensive." "Well, how are you on the offensive?" "W-w-we d-d-don't know, w-we haven't h-had the b-b-ball."

It is quite true that the United Nations have not had the ball very much in this tough struggle that we are in. But we are going to get the ball, and when we do get it, it is going to take the best kind of teamwork that our country has ever indulged in. We are going to have to have the coöperation of the organized groups from the top to the bottom of our whole fabric, and the home front has to play a major role in this war or the other part of this team that is delegated to play the front line can't win.

What day was it that the Japs raided Dutch Harbor? It was the third day of June. For one hundred days there have been enemy Japanese on American soil. How many of them? I don't know. Some folks say ten thousand, some folks say thirty thousand. Let us give them the benefit of the doubt and say there are only ten thousand Japs on Attu, Agattu and Kiska Islands in the Aleutians. Ten thousand Japs, well equipped with dynamite and tools, can construct some underground hangars, and they can build landing fields where they can base planes which can easily upset any plan that we have to carry goods

across the Pacific to aid the Russians when the Japs move into Siberia. They can base planes there with which they can easily attack Alaska and the West Coast.

How many of you heard Ambassador Grew last night? Nobody? Joseph C. Grew came home after the hard job that he had in Japan, and he said, "This country must stop groping, they must be brought to a realization that the Jap is sincere and honest in his belief that our way of life is wrong and that Japan is destined to rule this country." There is not any question about our becoming a have not nation and the Japs becoming a have nation, very fast. The Japs have the rubber and the tin and we have not.

Then I want to remind you of another thing, and that is about those two D's that Barney Baruch spoke about so well the other day —Discomfort or Defeat.

There is not any question about our aims in this thing, what we mean to do, the resolutions that the organized groups that we belong to have passed. But I would like to bring home to you gentlemen this afternoon that this is our country, our republic, our democracy. We like it here, we would not want to be anywhere else. But this is a struggle for life or death, and until we, as individuals, can cheerfully and honestly and sincerely say, "Here is what I have got; I will lay it on the line so that I may have it ten years, fifteen years, twenty years from now, so that my boys and girls can have some of the same advantages that I did"—until we can do that we are not coöperating one hundred per cent. We have got to do that individually before we can do it as organized groups, and to keep it straight I want to read something that Harry Emerson Fosdick wrote not long ago:

> "Naziism, Fascism, Militarism, the growing elements of dictatorship in the democracies—are all endeavors to get some kind of order out of chaos. . . . Either we are going to have enough people who discipline themselves from within, or else we are going to have discipline imposed on us from without. . . . Nothing left loose ever does anything creative. No horse gets anywhere until he is harnessed. No steam or gas ever drives anything until it is confined. No Niagara is ever turned into light and power until it is tunneled. No life ever grows great until it is focused, dedicated, disciplined. One of the widest gaps in human experience is the gap between what we say we want to be and our willingness to discipline ourselves to get there. And the cost in every realm is always self-discipline."

Now, we need coöperation, we need teamwork. And that reminds me—the desperate need for teamwork—of a letter that Coach Lloyd Jordan showed me the other day over at Amherst College. He hears frequently from Amherst men wherever they may be in the four corners of this earth. This was a letter from a former captain of a football team, which is a place where they learn about teamwork in Amherst. In one sentence he said: "I am sure you will be interested to know that many of the fellows who did not come back from Midway were those men who played the grandstand game on the gridiron." There is a commentary on teamwork, the kind of teamwork that this country of ours has got to have.

So the thing I want to leave with you, if I can, this afternoon, is to have you understand and feel the need for total coöperation, for all-out team play. Can't you see the desperate need for pulling together, this civilian protection thing, this concentration of noncombatants wherever they are? The auxiliary police and fire forces simply must play ball with the professional police and fire forces. Any feeling that may exist against the auxiliary fire and police personnel will be sincerely regretted when the professionals have a bigger job to do in thirty minutes than they can possibly do alone in thirty days. We can do our best only by coöperation.

If you have a lot of tough things in the back of your head that you are going to contribute to the winning of this war, please remember the old Chinese proverb: "The journey of a thousand miles begins with a single step." If you have got all these different things that you are going to contribute, let us not put them off any longer, let us take the first step, because I don't know, and I don't think anybody else knows, whether this journey is going to be a thousand miles or not. Today is the two hundred and eighty-second day that our country has been at war, and who is there who wants to take a wager that another two hundred and eighty-two more days will go by without a serious attack on this homeland of ours?

I would just like to read you now a new set of Ten Commandments, by Gill Robb Wilson of New Jersey. They are as follows:

"1. Thou shalt keep thy mouth shut.

"2. Thou shalt stay out of Washington; both thou and thy conventions and thy car and thy family and thy family's family, and all thy correspondence and

thy personal problems; none of these shalt thou bring to Washington, for they clutter up the works.

"3. Thou shalt not harass thy son because he hath not a commission; neither shalt thou make him to feel the service of an enlisted man to be beneath his college education and thy colonial background; neither shall these things be held against him by other enlisted men if thou dost not make of them an abomination.

"4. Thou shalt not hoard; only the squirrel hoardeth, and this he doth because he is a squirrel.

"5. Thou shalt not get ants in thy pants to put on a uniform only because thou art vain and hath no courage to hoe thy row in the place where thou art most needed.

"6. Thou shalt walk; even thus shalt thou aid to save gas and rubber; thus shalt thou redeem the price of thy girdle and thy doctor's bill and thy very hide.

"7. Thou shalt not strike; neither shalt thou walk out; neither shalt thou lock out; neither shalt thou sit down on the job; in order that thy days may be long in this land.

"8. Thou shalt not in thy confidence measure the seas, for verily they who have thought to hide behind the seas are full of prune juice.

"9. Thou shalt not fret because of evil-doers for thou hast not done so well thyself.

"10. Thou shalt not lose faith; thou hast lost nothing beyond recovery if thy faith be not lost."

WATER—A CRITICAL WAR MATERIAL

BY ARTHUR E. GORMAN*

[*Read September 15, 1942*]

It is obvious that the impact of this war with its serious dislocation of our national economy and its diversion of man power from civilian to military and war production efforts would affect such a basic commodity as water and the services by which water is supplied for domestic, commercial and industrial uses. The extent to which this impact is felt will depend on many factors, among which are: the length of time the war lasts; the extent of property damage by enemy action; the effectiveness of our organization to protect water systems and conserve the supply; and our fortune—good or bad—with regard to that uncertain but fundamental factor of water supply, namely rainfall.

The author welcomes this opportunity to present to the New England Water Works Association from the point of view of the War Production Board some aspects of war-time water problems that appear to lie ahead, and to suggest ways by which the water works officials can coöperate with the Federal Government to aid in solving these problems. The water works profession has been and is alert to its war-time responsibilities. In many ways, it leads other professional groups in initiative and purposeful planning to meet the exigencies of war conditions. But with the prospect of a long war ahead and Pearl Harbor only nine months behind, it is timely and proper that we should appraise the results of our past efforts and strike the forward course based on conditions as they exist and those which we can forecast with reasonable accuracy and acumen.

That water is a basic war commodity is a fact all water works men know well. That water is likely to become a critical war material they already may have suspected. But do they know that in certain sections of the country water supply deficiencies may cause severe bottlenecks in the nation's war effort? The water works profession

*Chief, Water Production Section, Power Branch, War Production Board, Washington, D. C.

has a deep responsibility to this nation; one that calls for profound patriotic planning of the most intensive character. Let us see why.

War production plants are calling for power and more power; the finished products for front-line fighting require careful processing of raw materials; this calls for machines and man power; machines must be repaired and replaced; men who operate and repair machines must be fed and housed; each of these items of our complex war effort—power, processing, machines, and men with their food, housing, and safety requirements—is dependent on the commodity water.

An adequate water supply depends on nature's gift of rainfall and man's ingenuity in constructing works for collecting, storing, treating, and distributing this resource. New water works structures and equipment require critical materials and man power—the two fundamental elements in a nation's war effort. Water is a basic and critical war commodity, the production and use of which must be intelligently and effectively integrated into the whole pattern that is to represent our nation's force in war; and let us not forget that this is the greatest of all wars recorded in history!

Intelligent water supply coördination of thousands of systems into the nation's war effort calls for coöperation of high order, if a maximum of service is to be obtained using a minimum of critical materials. We Americans have set high living standards for ourselves; and not the least of the services contributing to our high plane of living is an abundance of water available at relatively low cost. Already, war has affected our living standards, but not to the extent of any serious curtailment of water services. If we have a long war, it is not unlikely that water service will be considerably affected.

To maintain efficient public water service, requires maintenance of equipment and certain normal extensions to the water system. This calls for the use of critical materials. There are already desperate shortages of our most important of these materials. The restrictions already imposed on their use in order to conserve our limited supplies are certain to become even more stringent. These are plain facts we must face; and we should plan accordingly.

New England water works officials have been unusually alert to their war problems. They have coöperated splendidly in postponing normal betterments and by organizing mutual aid inventory sys-

tems in extending the service of existing supplies for emergency use and thereby limiting the purchase of additional equipment. There is some evidence that the Civilian Defense Program of the region did add to normal inventories, but the author understands that releases are being made to cut back to the 1940 level as required under the P-46 Limitation Order.

As a result of conferences held during this convention, it is expected that a coöperative program can be established which will make available to the War Production Board certain important records of critical material inventories compiled by New England state coördinators and this Association. At this time, it is only fair to say candidly that it is likely that water works inventories will have to be cut considerably before they can again be allowed to return to the 1940 level. Most of us probably realize that, under present conditions, this is inevitable.

The call on many water works systems for additional service to war industries and to military establishments has been heavy. In some cities and districts, this demand came early before materials were scarce. Facilities that were taxed to capacity were relieved by the installation of additional equipment or by making certain major extensions to the system. In other cities, however, the pinch of the war demand is just beginning to be felt and may not reach a peak until next summer. The hope of obtaining any considerable amount of critical material with which to provide assistance is diminishing.

Every effort will be made by the Power Branch of the War Production Board—which now initiates recommendations for critical materials to water works—to provide, within the limits of allotments for such requirements, an equitable distribution of critical materials to the water utility. In doing so, consideration will be given to the effort that management of this utility has made to obtain effective capacity to meet additional consumer demands by a reasonable water conservation program. Priorities for materials and equipment to maintain pressures at times of ridiculously high maximum hourly demand peaks should not and will not be granted.

In some sections of the country, the abnormal use of well water in new war plants is beginning to cause a serious recession of ground water, not only robbing other plants of their share of underground

water, but threatening to curtail war production. Where vital industries were concentrated and ground water shortages were threatened, the Federal Government, in a limited number of cases, has arranged to finance projects requiring a minimum of critical materials to bring a supplementary supply of surface water into the area to relieve the heavy drain on the underground supply. Intrusion of salt water into fresh water aquifers might prove disastrous to certain industries depending on fresh water from wells. Furthermore, corrosion of metals caused by the high salt content might destroy or damage vital operating equipment, with accompanying delays in production and the necessity of replacements requiring additional critical materials.

There is evidence that in the past, at many industrial plants, critical materials have been used in the construction of wells when an ample and adequate supply of water was available from public systems having mains adjacent to these premises with capacity to meet the demands of the industrial plant for all purposes, including fire protection. Small differentials in rates between plants within and outside the corporate limits of a city have been the basis of decisions to construct wells rather than purchase city water. This type of economy at the expense of critical materials must not be repeated. A few hundred dollars extra per year for the purchase of city water is a small price to pay in order to provide the critical materials for more weapons for our soldiers at the front.

Let no one urge in such cases that the city might be delayed in getting materials to serve this potential consumer. If the specific facts are brought to the attention of the War Production Board promptly, there is no occasion for serious delay under the priorities system. Present the complete economic picture as to critical materials and water service and supply, and the Board will do its part in assisting water departments to obtain needed materials to serve any war industry whether the materials are requested under a PD-1-a or a PD-200 application.

If the reader could serve but one day as an analyst or as a priority expert reviewing the types of applications that many water works officials have sent in, he would have a full appreciation of some of the administrative difficulties involved. He would agree that many of

these applications should never have been submitted. Others, while undoubtedly justifiable, he would find so vague and indefinite that he could not make a good appraisal of the necessity for the project or the equipment for which a priority rating is requested. The filing of fewer applications will permit better processing and prompt action on essential ones. It is probable that some new forms for reporting the weights of such important critcal materials as steel, cast iron, copper, brass, bronze and rubber will be issued in summary form in the near future. They may also call for a schedule of the period during which these materials will be needed. This will permit better budgeting of supply to demand.

Under the acute strain of this war on both critical materials and man power, all of us must bring ourselves to a state of super-war consciousness; one that would forbid us to submit to the War Production Board a priority rating application for materials that we can possibly get along without. We need more Yankee ingenuity in making what we have been accustomed to call obsolete equipment serve another year or two. We have not begun to use the second-hand material and supply market to its full potentialities; nor are we salvaging equipment and parts to the extent we should, considering the shortage of base metals.

Our water resources should be guarded jealously during the period of this war where victory will only come when the enemy has exhausted his resources. If this war turns out to be a long one, there is a possibility that in certain critical areas, where deficiencies of supply may develop, water may have to be allocated to assure an adequate amount for war purposes. Everyone is hopeful that allocation of water will not be necessary. But since it is a possibility, especially where underground and impounded surface supplies are used, water works officials should watch with care the effect of war demands on available supplies. They should plan a conservation program which should be put into effect progressively as required. Conservation methods applied early enough in a season may carry a system through a prolonged dry spell. Here in New England with its impounded surface supplies there should be full realization of what rainfall deficiency means.

The use of water for air conditioning for comfort, the sprinkling

of lawns every day of the week, and the unnecessary flushing of streets from fire hydrants are special examples of where curtailment of use should be put into effect.

Water should be used efficiently at all plants that require large quantities of it. Water should not be released to the sewer until it has served all possible useful purposes. If the supply is obtained from underground sources, means should be considered of making use of the spent water to help recharge the watershed. Clean cold ground water should not be used for purposes for which an available raw surface supply would be satisfactory. Water used for make-up to condensers and other heat-exchange units should be kept at a minimum by the use of efficient cooling towers, preferably with forced-draft equipment.

In conclusion, the author should like to restate in summary form the following ways by which water works officials can help themselves and the War Production Board in its effort to expedite the Nation's war effort:

1. Coöperate with the state coördinator in maintaining complete and up-to-date water works inventories.

2. Coöperate with all industrial consumers engaged in the war effort and render as complete service as possible from the public system, thereby making unnecessary the expenditure of critical materials for private water systems.

3. Do not apply for priority preference ratings unless this request has been cleared through your own conscience priority system; then make the application complete and specific.

4. Make a strong effort to prolong the life of existing equipment through good maintenance and early repairs; and salvage as much critical material as possible.

5. Plan a water conservation program for the system. Keep accurate records of supply and demand in order to know where to apply this program to assure protection against a shortage of supply.

6. If acute shortages are anticipated consult the War Production Board and we will do everything we can to assist in developing a program to help meet them.

7. Do not come to Washington with reference to your project application unless you are invited specifically to do so.

Mr. Herbert S. Marks, Chief of the Power Branch of the War Production Board, has asked the author to extend to this Association and the officers of the New England state association his thanks and appreciation for the fine spirit of coöperation shown in New England toward the War Production Board in its administration of water utility services and especially for the coöperation of the state mutual coördinators in making available the records of surplus water works inventories.

WAR TIME PROBLEMS IN THE PORTLAND WATER DISTRICT

BY F. J. RENY*

[*Read September 16, 1942.*]

In order to understand the war problems in the Portland Water District, it is necessary to know the background and history of the Portland Water Supply. The author will, therefore, outline briefly the situation in Portland as he found it in September, 1904, when he became associated with these works.

History. At that time, the water works in Portland were owned and operated by the Portland Water Company, a private corporation. The source of the supply was Sebago Lake a practically inexhaustible supply of pure water. This lake is approximately 4 miles wide and 12 miles long, with an area of approximately 46 sq. miles. Its elevation is 270 ft. above mean low tide at Portland, so that water could be secured by gravity. The distance from the City is approximately 17 miles.

The system at that time consisted of two cement and iron transmission mains; the first laid in 1869 and connected to a 10-m.g. reservoir on Bramhill Hill in Portland, and the second a 24-in. and 26-in. cement-lined pipe installed in 1879, the two mains being interconnected by 30-in. cast-iron pipe for a portion of the distance. Water was later stored in a second reservoir in Portland on Munjoy Hill, with a capacity of 20 m.g., a standpipe erected near the Munjoy Reservoir with a capacity of 653,000 gal., and a standpipe in South Portland across the Harbor with a capacity of 602,000 gal. The capacity of this system at that time was 8½ m.g.d., and the population supplied approximately 90,000. There were in the system 12,000 services, of which about 1500 were metered. The system was divided according to elevation into high- and low-service districts with intermediate gates between these systems. All of the area above elevation 90 was called high-service, and that supplied by gravity from the reservoir below elevation 90 was designated low-service.

*Treasurer and General Manager, Portland District, Portland, Me.

The problems of supply during those days were not intricate. The company could not well be called a one-horse concern, because it had three horses, and one piece of equipment, a two-horse jigger to haul lengths of pipe from the shop to the trenches. The rate of pay of workmen in the street was $1.25 a day; men of experience received $2.00 a day; and the very best men were paid $15.00 per week, this being regarded as tops in wages at that time.

Most of the pipe in the distribution system had been changed to cast iron, with the exception of a few dead-ends, but grid-ironing was sparsely done in the closely built sections. Hydrants were widely separated, and very little attempt had been made to create a fire reserve. Water was supplied to several communities outside of Portland proper, Portland and South Portland being the main areas, but Cape Elizabeth, Falmouth, Westbrook, Gorham, and Windham were also served by the company during this period. Up to and including the year 1907, there had been more or less controversy regarding water rates, and the citizens had formed a real estate tax payers' association and had definitely aligned themselves against the private corporation operating the water works. Due to agitation, principally by this tax payers' association, but also by others, a charter was secured in the Legislature in 1907 to incorporate the Portland Water District and to take the works over by right of eminent domain. An election was held in the fall of 1907, and the citizens of Portland and South Portland voted to form a water district and to take over the works of the Portland Water Company. Trustees were elected, four from Portland and one from South Portland, and the District was incorporated and took charge of the works officially on May 1, 1908. The court before which the hearing was held saw one of the greatest legal battles ever held in the State of Maine. Some of the finest lawyers in the country and some of the greatest engineers in the country were called into consultation at the time. We all remember Allen Hazen, Leonard Metcalf, and others of like capacity, and these men were engaged to testity in this case.

At the end of the proceedings, the referees awarded to the old company as the value of the works the sum of $2,600,000 and in addition $1,200,000 for going value, good will, or what have you. This award with the added cost of the hearings, attorneys, fees, etc.,

brought the cost of the taking to nearly $4,000,000. The figures were finally agreed upon, the new Trustees assumed their duties on the first day of May 1908, and the Portland Water District started to minister to the water needs of the public from that date. The new broom began to sweep clean, and all of the old-time executives were released with the exception of a few of the younger men. The author was one of those retained by the District.

At about this time, the adequacy of the water supply of Portland was much discussed, as the engineers at the hearings had testified that the system was capable of delivering only 8½ m.g.d., that the daily use was well up to this amount, and that this left nothing for fire reserve whatsoever. Several large fires that occurred at that time had proved that the engineers were right, that no fire reserve existed, that the mains were inadequate, and that the system was not able to supply the needs of the water takers and the fire reserve as well. Consequently, in 1912, the Trustees decided to construct an additional 42-in. main from the lake to the city. Contracts were awarded, and the work was finished in the fall of 1912. The new 42-in. cast-iron main increased the capacity by 23 m.g.d. Also, in addition to this transmission main, the system was further reinforced by the extension of distribution mains, the increasing of grid-ironing, and the making of other needed repairs. A million dollars was spent for improvements of the plant during the year.

A question was raised regarding the purity of the water. The raw water had previously been taken from the lake without purification except screening. It became apparent that some method must be devised to ensure the purity of the water for the reason that the lake shore and islands in nearby locations to the intake were covered with cottages. During the year 1914, therefore, was begun the first crude chlorination of the water with hypochlorite of lime. The chlorinated lime was dissolved in large containers installed on neighboring brooks and fed into the brook water. The drainage from other points was treated in like manner. The water carried by the 42-in. main which had just been installed was chlorinated through a large container of hypochlorite, provision being made to discharge a certain amount of chlorine into the main daily. This was the first disinfection started by the District. It soon became apparent, however, that all

of the lake shore near the intake would have to be protected against pollution. During the next year or two, therefore, every one of the cottages in the lower bay of the lake was bought up, dismantled, and removed. Eventually this led to the establishment of a two-mile limit, in which the Trustees of the District were authorized by the legislature to prohibit all swimming and other forms of pollution that would tend to injure the purity of the water. Several hundred thousand dollars were spent to buy the land around the intake and so to safeguard the purity of the supply. Later on it was found that automatic chlorinators supplied with liquid chlorine were more efficient and more easily operated. Suitable equipment was purchased from the Wallace & Tiernan Company and controlled purification was really born at that moment in the system of the District.

Meanwhile, further additions to the plant of the District had been made. As the years progressed, it became necessary, in 1926, to abandon the old intake because its capacity was insufficient. The hydraulic grade of the tunnel had never been steep enough to provide a large flow and the acquisition of new mains presented the choice of pumping water or securing an intake with adequate capacity. Accordingly, in 1926 the new intake was installed and a 54-in. pipe was extended into the deep portion of the lake where more than 30 ft. of water covered the intake during most of the year. The intake was completed during the fall of 1926 and piped to the purification buildings, a mile below the lake itself. Here was installed the purification equipment under the supervision of a resident chemist employed for that purpose, and samples of the raw water and the water as delivered at the office building in Portland were examined each day.

These improvements, together with the additions to the system, had created a fire reserve that was now considered to be comparatively adequate for the territory supplied. However, in 1929, it became necessary to abandon portions of the first cement-pipe main which was located along the route of cement roads to be built by the state, and to find a new route outside of the traveled way.

During 1929, contracts were let to the Lock Joint Pipe Company of Ampere, N. J., for the installation of several miles of 48-in. steel and reinforced concrete pressure pipe, with the idea of constructing the transmission system of the District in such manner that duplicate

mains would be provided when the final work was completed. During the fall of 1929, these large pipes were installed, and much of the former 20-in. line discontinued. In 1939, during the period when Public Works Administration funds became available, it was decided to complete the balance of the 48-in. main to the lake. This contract, too, was awarded to the Lock Joint Pipe Company together with a contract for all of the cross-connections and work that would complete a dual system of supply mains. The work was completed in the fall of 1939, and fortunately for the District, 45% of the cost was paid by the Public Works Administration.

When this work was completed, the Trustees of the Portland Water District had brought the system up to a point where the population supplied by Sebago water was now served by a system of dual mains, each one capable of bearing the load of the service separately or collectively as desired, and the completion of this work gave the Portland Water District one of the few Class-A ratings for insurance purposes in the country. In the meantime the use of water in the system had increased materially with the acquisition of the Scarboro system in 1915 and the system of several other outlying communities. At the present, the Portland Water District is supplying 16 subdivisions. An emergency pumping station is situated in Portland through which water could be made available during an emergency by pumping water from the reservoir. The system has a capacity of more than 75 m.g.d., with a daily use of from 15 to 18 m.g., so that the margin of fire protection is far beyond the usual. The present valuation of the system is approximately $12,500,000. The territory supplied is about 20 miles on a side.

The author confesses that this description has little to do with war-time problems of the Water District, but he believes it necessary to acquaint the reader with the situation in Portland so that he may know what has to be protected in war time, how well the system has been built, how thoughtfully and carefully the system has been added to section by section, little by little, until the citizens of Portland and vicinity have been assured of a more than adequate supply of the purest available water without increased water rates. In fact, water rates are less.

The problems of the water superintendent of a system such as

the author has described, the reader will agree, must be considerable in war time. The author believes that they fall relatively into the following classes: first, personnel and the education of personnel; second, routine and coöperation with the Civilian Defense; third, labor; and fourth, material and equipment.

Personnel. In regard to personnel, it must be understood that all of the personnel of the water department must first be examined as to its qualifications for employment during the war-time period. Therefore, the first move made at Portland was to have every person in the employment of the District registered under F.B.I. specifications, photographed and fingerprinted; all of the reports were filed with each man's employment record, and identifications were issued to each worker who was a bona fide employee of the District. An identification button was provided to be worn at all times, numbered, and recorded in the office. Identification cards in a little leather case, each card bearing the signature and photograph of the bearer, and the seal of the District so that they cannot be duplicated, were also issued to each employee.

Maps of the system were prepared and put into such shape that any section of the District can be picked out at a moment's notice in case of emergency. A copy of these maps was given to the Civilian Defense heads so that we would talk about the same things in case of emergency.

Personnel was split up into divisions, and each foreman or responsible person having the required amount of experience was given charge of zones so that every zone would be represented by at least one workman and two men to aid him. The equipment for these zonemen included a canvas knapsack to be worn over the shoulders and containing a gatebook with all the measurements of the zone therein, also a 100-ft. tape and a flashlight. The gate wrenches belonging to the different zones were placed at some convenient location that will be handy of access in the zone. In case of emergency, each workman receiving his directions from his superior is directed to go to the zones indicated and there assume control.

Guarding. In addition, there devolves upon the District the provision of special protection or guards. Immediately upon the start of hostilities, we received an order from the Civilian Defense head to

place guards upon the system at the earliest possible moment. Applications were, therefore, secured from men desiring to do guard duty, and they had to be fingerprinted, photographed and vouched for as bona fide American citizens. At the same time the points in the system where the guards were to be stationed had to be picked out. We found that there were several places where it was necessary to maintain permanent guards. It was decided to pay these men $4.00 a day for eight-hour duty, and to have three shifts a day. In two days we had our organization completed and our Board of Trustees had authorized guards to be placed at certain essential points in our system. The men were sworn in as deputy sheriffs and given a badge as the symbol of their authority. They were armed with shotguns loaded with buckshot and placed under the supervision of a hard-boiled captain of the guards. This captain is the key man because we must rely upon him to see that the guards are constantly on the alert, that they are checked up at least twice a day, and that, if there are indications of inattention to duty or any other suggestion of indiscretion on the part of the guard, his services will be immediately dispensed with and a new man secured. The job of guarding is a tiresome and uninteresting one. At the end of a week, men become careless and if they are not checked up constantly they are likely to become inefficient. Our 19 guards have been changed to some extent since last December.

In addition to the question of guards, there also arose the question of protection of the structures involved. This meant thousands of feet of fencing that had to be purchased and erected. Luckily we saw some indications of war and the fences had been already purchased by the time the war broke out. The installation of floodlights was another part of this work, and suitable lights were shortly in position and are ready for use when necessary. Signs, notifying the public to keep out are also in place.

Telephone communication is arranged with all the local telephone stations, as well as station to station calls. All of the local station to station material was installed by our own men and with our own equipment.

Our guards, at the present time, are costing us between $500 and $600 a week, and the total cost will exceed $30,000 per year. Every

attempt was made, at the first of the war period, to secure Federal guards for the water works, as our Trustees believed that the guarding of the water plant and submarine lines to the fortifications on the islands in Portland Harbor was of very great importance to the Federal Government. Accordingly, applications were made to General Wilby in Boston for Federal guards, but the application was immediately denied. Further applications to other officials in the same zone led to the same results.

All of us are convinced of the importance of water supply in time of war. We have heard members of our Association, who served with the A.E.F. in the first world war, state that a special water service unit was created, and that it was one of the most important parts of the Army program to provide adequate amounts of chlorinated water that could be used safely by the Army. Other utilities may be as important in their service to the Army as water works. We all know that wars have been fought without telephones, and without electric lights, but I doubt if any of us ever heard of a war that was fought without water. All history that the author has ever read refers to the cries of the wounded as they lay upon the battlefield, and almost without exception the call was not for mother or Deity but for a drink of water.

Civilian Defense. Immediately upon the outbreak of hostilities, our whole organization was incorporated into the routine of Civilian Defense. Each man was assigned a specific duty, whether it was driving a truck, going to Civilian Defense headquarters to be a telephone man, or reporting to the office for the relaying of messages. Every man has now performed those duties well. In two blackouts and several practice air raids, our organization has had an opportunity to see how the organization would function in an emergency.

In passing, mention should be made of the question whether or not we should pay men who are asked to assist us in case of an air raid. Our organization has called into conference more than 50 plumbers, steamfitters, and helpers who have been organized to help us in an emergency. The author believes that all men should be patriotic in answering the call to duty in an emergency, but also that men who lose a portion of their day's labor or who contribute a portion of their equipment should logically be paid for their services.

This statement is made because Civilian Defense has been rapidly organized on the basis that all services should be donated without pay.

Labor. The question of labor in war time is a very important one to all of us. We have been accustomed to having men approach us in the springtime requesting that they be given work. During the past year, however, that type of labor has been extremely difficult to find and laborers have sold their services to the employer who offers the greatest amount of pay. No criticism can be made of a laborer who desires to better himself, but no water department can compete with the wages paid to common labor by contractors and other large industrial concerns. The average water department has to be run on some kind of a budget, and additional operating expenses are not readily absorbed. Increased wages for common labor, furthermore, would certainly cause the water department to revise all wages upwards. However, inasmuch as the National Government has allowed wages to be paid, which in some cases are two to three times as much as the workman ever earned before in his life, it has forced the water department, which has lost many of its men to these highly paid jobs, to sit back and apologize to its water takers when something occurs that demands quick service.

In Portland, we always prided ourselves that we had established what we were pleased to call a "super service." We could send a truck at almost any minute of the day or night to take care of difficulties. It is extremely embarrassing and humiliating, now, to have to say to our subscribers that we cannot give them the attention that we formerly did because we do not have the personnel that we formerly had.

Materials. As to materials, it seems as if all of the water departments throughout the country knew that there was going to be a war. The author does not claim that he is gifted with second sight, but most certainly if one reads the papers and tries to imagine what is going to happen next, one must have seen that continual war preparation by the Allies would eventually cause the United States to become involved. This was evidently apparent to all water works men, and we have been notified that our materials and supplies in some cases are in excess of what the War Production Board says we should have.

Having had some experience in the previous war and seeing what

a war does to a water works, the author will admit that in Portland we felt that there was going to be a war. We knew beyond all question that when war came it would be impossible for us to purchase the materials that we knew we might require. It seems rather strange to us, however, that the War Production Board should have placed the amount of inventory that a water department should have as of December 31, 1940, because the usual water utility has the smallest inventory at the end of the year and it is the usual practice to purchase in the spring. Most of the small utilities had very little in the way of inventory on December 31, 1940, and many of them immediately took steps to secure material because they knew that it would be necessary.

In Portland we found it necessary to buy additional material, because of the influx of about 20,000 workmen, in connection with the construction of two shipyards in South Portland, and the completion of the oil main from Portland to Montreal. Large pipe lines were needed to reinforce the system, and if such pipe had not been available most certainly the shipyards could not have gone into production as soon as they did. To supply water to the shipyards and other necessary industrial installations, we had to spend thousands of dollars. To make way for the shipyards, hundreds of homes had to be torn down, and this led to a shortage of housing. Housing requirements in Portland have again demonstrated the wisdom of the purchase of materials that had been made by us for these purposes and others during the war period. By actual figures we find that more than 2000 housing units are needed in the Portland area. Recently, more than 146 housing units have been completed in the Cape Elizabeth section. This housing development required the installation of more than a mile of 8-, 6-, and 2-in. mains, as well as the services to each house. Certainly no one could criticize the water utility for having this material on hand. In addition to this development there has been approved by the War Production Board more than $20,000 worth of installation of material for housing projects. The question is, shall we have the material to install these developments on hand, or shall we wait and get a priority. The latter would take us, according to the best figures obtainable, from six to eight weeks. By that time the winter will be upon us, and there will be very little chance

of the usual construction. Therefore, it would seem to the author that the water department heads, who, having had certain experience in the past, realized war means material and that war means water service, should not be criticized for this foresight but that they should be acclaimed by the rest of the country as the leaders of one branch of industry who had their eyes wide open and that their desire to serve should be pointed to, as it always has been, as the prime desire of all water utility men.

STUDIES ON THE REMOVAL OF IRON AND MANGANESE FROM WATER

BY EDWARD W. MOORE* AND ERNEST A. SNOW†

[*Received August 28, 1942.*]

The treatment of water for the removal of objectionable quantities of iron and manganese is one of the earliest examples of the application of chemical and engineering knowledge to the art of water supply. Weston states that the removal of iron by aeration and filtration was successfully accomplished on a large scale by Salbach as far back as 1868, and it is evident from a reading of Weston's papers that much that still persists in present day practice was developed before the beginning of the present century. Historically, iron was the first to be recognized as an offender, and manganese was not taken seriously until the Breslau "calamity" in 1906.

With few exceptions, the plants designed for the removal of iron and manganese have been based on the oxidation of these materials to insoluble ferric and manganic hydrates, and elimination of the hydrates by sedimentation and filtration. The means of accomplishing this oxidation are varied, and chemicals are often used to assist the oxidation or coagulation processes. Iron and manganese have been commonly treated together, although manganese has been recognized as more difficult to remove. The literature on iron and manganese removal is too extensive to permit citation of more than a few of the later references.

The history of manganese in water supplies has been thoroughly reviewed by Zapffe in a paper that also contains an excellent critical analysis of the theory and practice of its removal. According to Zapffe, the theories advanced to explain the precipitation of manganese from water include oxidation and precipitation by bacteria, direct chemical oxidation followed by precipitation, and catalytic action. It is brought out in Zapffe's paper that much theorizing has been based on little experimental evidence, and that the development

*Associate Professor of Sanitary Chemistry, Harvard Graduate School of Engineering, Cambridge, Mass.
†Assistant Chemist, Massachusetts State Department of Public Health, Boston, Mass.

of a well-grounded theory of manganese removal has been retarded by the assumption that the mechanism of removal is necessarily the same as that for iron. This assumption has been generally accepted despite the fact that it was evident from practical experience that manganese was not efficiently removed except in the presence of active surfaces of manganese dioxide. These surfaces could be provided either by allowing some contact material such as coke or sand to become coated with deposits of the oxide, or, as in the work of Zapffe, by the use of beds of pyrolusite mineral.

Tillmans and his co-workers have accumulated evidence to show that the mechanism of manganese removal consists essentially of adsorption of divalent manganese ion by surfaces composed of hydrated manganese oxide. The adsorption is accompanied by the release of hydrogen ions in quantities corresponding to the manganese adsorbed. Oxidation of the adsorbed manganese takes place subsequently, and according to Tillmans and his co-workers, bacteria play an important part in this process.

Although Tillmans used in his experiments suspensions of precipitated manganic hydrate or hydrated oxide, he does not seem to have regarded such materials as having any practical possibilities beyond the investigation of the mechanism of manganese removal. However, it has occurred to the senior author of this paper that an analogy exists between the processes of iron and manganese removal by contact and oxidation, and the biological treatment of sewage. In the latter, the use of a suspended contact medium, as in the activated sludge process, has been found to offer more efficient operation than that obtained from a stationary contact medium, such as the trickling filter. If the analogy is valid, the substitution of a suspended active sludge of some sort for the stationary contact beds of coke, sand, or pyrolusite might offer similar advantages.

It is the purpose of this paper to describe and discuss laboratory experiments directed toward investigating the possibilities of such active sludges, the ways in which they might be produced, the conditions under which they might be effective, and the advantages, if any, that they might offer. The results of these experiments are believed to be of interest in relation to both the theory and the practice of iron and manganese removal.

Experimental Methods. In studying the effect of surface active materials in the laboratory, the technique employed was relatively simple. Since the active materials were prepared in the form of heavy suspensions or sludges, it was sufficient to mix a definite proportion of the sludge with the particular iron-and-manganese bearing water to be studied, adding at the same time any reagents necessary for pH control. The sludge was allowed to remain suspended in the water for a specified period and then removed by filtration, repeated if necessary to secure a filtrate free from finely divided sludge particles. The iron and manganese remaining in the filtrate were determined in accordance with Standard Methods of Water Analysis of the A.P.H.A.

Waters Employed. The iron-and-manganese bearing waters used in these studies were all well waters and were obtained from the raw-water lines of the Lowell, Brookline, Cohasset, and Methuen, Mass., water plants.

TABLE 1.—YEARLY AVERAGE ANALYSES OF WATERS USED IN EXPERIMENTS. ALL RESULTS EXCEPT pH VALUE ARE EXPRESSED IN ppm.

Source	Brookline		Lowell		Cohasset		Methuen	
Year	1939	1940	1939	1940	1939	1940	1939	1940
Color	59	55	43	48	109	83	1	18
Total Solids	108	108	64	71	76	85	84	66
Free Ammonia *N*	0.081	0.080	0.152	0.148	0.061	0.048	0.332	0.199
Albuminoid *N*	0.081	0.064	0.055	0.053	0.202	0.129	0.035	0.058
Nitrate	0.47	0.48	0.39	0.28	0.18	0.17	0.53	0.85
Nitrite	0.003	0.004	0.003	0.000	0.002	0.001	0.000	0.001
Chloride	7.9	8.7	3.9	5.0	10.8	12.2	7.9	7.0
Hardness	51	50	25	27	23	28	49	47
Alkalinity	48	44	19	21	15	14	48	51
pH	6.6	6.5	6.3	6.4	6.0	5.7	6.8	6.7
Iron	1.4	1.3	2.1	1.9	1.2	1.5	0.6	0.28
Manganese	0.65	0.42	——	0.43	0.33	0.28	5.0	6.2
No. of Samples Represented	9	6	7	3	5	4	3	2

Table 1 gives average analyses of these waters for the years 1939 and 1940, as an indication of their characteristics. These figures are taken from the reports and records of the Massachusetts State Department of Health. The waters were chosen to obtain as wide a

range of characteristics as possible within a reasonable distance from the laboratory, since it was considered that samples more than a day old were of little value for the experiments. The waters from Brookline, Lowell, and Cohasset each contain from 1 to 2 ppm of iron, and a smaller amount of manganese. Of these, the Cohasset water is relatively soft, acid, and high in color and organic matter. The Lowell water is less acid and contains less color than the Cohasset water. The water from Brookline is similar to that from Lowell, but somewhat harder. The Methuen water differs considerably from the other three. It is very low in color, almost neutral, and contains 5 to 6 ppm of manganese, but only a small amount of iron.

The Lowell, Brookline, and Cohasset waters are at present treated for the removal of iron and manganese. The Methuen water comes from a well now largely abandoned in favor of wells lower in manganese. At Lowell and Brookline, the treatment consists of aeration, passage through contact beds of coke, and filtration through slow sand filters. In 1940, the Brookline plant reduced the average iron content of the water from 1.3 to 0.14 ppm, and the manganese from 0.42 to 0.03 ppm. At Lowell, results were not as good, the final effluent showing an average of 0.6 ppm iron and 0.2 ppm manganese. At Cohasset, the water is aerated, passed through coke beds, coagulated, settled, and passed through rapid sand filters. Here the iron was reduced from 1.5 to 0.08 ppm, but the manganese was only decreased from 0.28 to 0.21 ppm.

Types of Contact Materials Used. The most important thing in a contact process involving either adsorption or catalysis is the nature of the contact surface. Therefore, it seems advisable to enumerate the contact materials tried and to state briefly the effectiveness of each in removing iron and manganese. The materials employed can be classified into the following groups in accordance with the methods used to produce them:

1. Sludges produced by mixing solutions of potassium permanganate and ferrous sulfate in stochiometric proportions, together with varying amounts of lime, powdered calcium carbonate, or other alkaline reagents. These suspensions were highly successful in removing iron and manganese from all types of water, and, unless otherwise stated, the results given in the body of the paper were obtained with materials of this type.

2. Sludges produced by reacting manganous sulfate and ferric chloride in the presence of ammonium hydroxide. These suspensions were able to remove iron, but were ineffective for manganese removal.

3. Precipitates obtained by continued aeration from Lowell, Mass., raw water, which contains iron and manganese. These materials were unable to remove any significant quantity of iron or manganese from subsequent portions of water.

4. Sludge obtained from the filters at the Lowell, Mass., iron removal plant. This sludge removed manganese but not iron at first, and later lost the power to remove manganese.

5. Suspensions produced by reacting potassium permanganate and ammonium oxalate under alkaline conditions to produce manganic hydrate. These sludges effected fair removal of iron, but little removal of manganese.

Since the sludges of class 1 seemed to be the most successful in removing both iron and manganese, they were used in the subsequent studies. These studies include the effect of time of contact with the sludge, the effect of aeration with or without sludge, the effect of pH and the reagents used to correct the pH, the effect of age of the sludge, and the effect of quantity of the sludge. As previously stated, four different waters were employed.

Effect of Contact Time and Aeration. The first factor to be investigated was the time of contact required between sludge and water in order to secure a satisfactory removal of iron and manganese. This time was surprisingly short in many of the experiments, as is shown in Table 2. Of course, it is necessary to consider the time spent in filtering the material as part of the contact time. The individual samples of water used in the experiments given in Table 2 had the following characteristics: Brookline, pH 6.7-6.9, alkalinity 40-50 ppm, hardness 56-70 ppm; Lowell, pH 6.3, hardness 30 ppm. All pH adjustments were made with clear lime solution.

The data of Table 2 lead to three conclusions. In the first place, the removals noted are definitely due to the action of the sludge, since mere pH adjustment, aeration, settling, and filtration of the water, even for a period as long as 16 hours, failed to remove more than 50% of the iron and manganese present in the water. Again, aeration of the mixture of water and sludge failed to effect any im-

TABLE 2.—CONTACT TIME IN RELATION TO IRON AND MANGANESE REMOVAL BY ACTIVE SLUDGES

Water	pH of Final Mixture	Treatment of Sample	Time of Contact	Time of Filtration	Manganese ppm Initial	Manganese ppm Final	Iron ppm Initial	Iron ppm Final
Brookline	6.8	Sludge, aeration	over night	15 min.	0.22	0.42	1.5	0.02
Brookline	9.2	pH adjusted						
		No sludge	over night	15 min.	0.22	0.20	1.5	1.5
Brookline	9.0	pH adjusted						
		Sludge	over night	15 min.	0.22	0.05	1.5	0.04
Brookline	7.1	Sludge, aeration	30 min.	15 min.	0.25	0.04	1.2	0.02
Brookline	7.9	Sludge, aeration	1 hour	15 min.	0.25	0.02	1.2	0.02
Brookline	7.9	Sludge, aeration	2 hours	15 min.	0.25	0.02	1.2	0.04
Brookline	7.9	Sludge	30 min.	15 min.	0.25	0.01	1.2	0.02
Brookline	8.1	Sludge	1 hour	15 min.	0.25	0.02	1.2	0.06
Brookline	8.0	Sludge	2 hours	15 min.	0.25	0.01	1.2	0.16
Brookline	8.5	No sludge						
		No aeration	½ hour	15 min.	0.25	0.15	1.2	0.60
Brookline	8.2	No sludge						
		No aeration	1 hour	15 min.	0.25	0.15	1.2	0.60
Brookline	8.5	Aeration						
		No sludge	15 min.	15 min.	0.20	0.18	1.0	0.70
Brookline	8.2	Sludge	15 min.	15 min.	0.20	0.03	1.0	0.06
Brookline	8.3	Sludge, aeration	15 min.	15 min.	0.20	0.01	1.0	0.04
Brookline	8.5	Sludge	15 min.	15 min.	0.20	0.01	1.0	0.04
Brookline	8.5	Sludge, aeration	15 min.	15 min.	0.20	0.01	1.0	0.02
Brookline	8.3	Sludge	15 min.	15 min.	0.20	0.01	1.0	0.04
Brookline	8.5	Sludge, aeration	15 min.	15 min.	0.20	0.01	1.0	0.04
Brookline	9.1	Sludge	0	15 min.	0.25	0.00	1.0	0.06
Brookline	8.4	Sludge	5 min.	15 min.	0.25	0.01	1.0	0.10
Brookline	8.6	Sludge	10 min.	15 min.	0.25	0.01	1.0	0.20
Lowell	8.3	Sludge	18 min.	15 min.	0.60	0.00	3.3	0.10
Lowell	8.2	Sludge	31 min.	15 min.	0.60	0.00	3.3	0.00
Lowell	8.0	Sludge	1 hr. 8 min.	15 min.	0.60	0.00	3.3	0.00
Lowell	7.9	Sludge	1 hr. 54 min.	15 min.	0.60	0.00	3.3	0.00
Lowell	8.0	Sludge	2 hr. 50 min.	15 min.	0.60	0.00	3.3	0.00
Lowell	8.0	Sludge	3 hr. 50 min.	15 min.	0.60	0.10	3.3	0.00
Lowell	8.0	Sludge	4 hr. 45 min.	15 min.	0.60	0.00	3.3	0.00

provement in the amount of iron and manganese removed. Presumably, the samples contained sufficient dissolved oxygen to oxidize the iron and manganese. However, the most significant conclusion to

be drawn from the data of Table 2 is that the contact action must be extremely rapid, since good removal was obtained even when the water-sludge mixture was filtered immediately after being made up. In this experiment, the contact period was not over 15 minutes.

The concentrations of iron and manganese remaining in the water after treatment with sludge and filtration were generally measured in hundredths of ppm. The results are therefore commensurate with those generally obtained in practice.

Effect of pH and Corrective Reagents. Early in the investigation, it was found that the pH value of the sludge-water mixture had a profound influence on the removal of iron and manganese obtained. In Table 3, some representative studies of the effect of pH adjustment are presented. The experiments cited have involved only the addition of sludge to the water to be treated, adjustment of pH, filtration after 30 minutes of contact, and determination of iron and manganese in the filtrate. In each experiment, the time necessary to filter the sample was approximately 15 minutes.

In general, the results given in Table 3 indicate that good removal of iron may be obtained at pH values as low as 6.5, but that a pH value above 7.0 is more desirable. There is evidence that removal of iron is sometimes adversely affected by pH values above 9.5, and below 6.0. As in experience with practical plant operation, the removal of manganese appears to require higher pH values than that of iron. If reduction of the manganese content to 0.1 ppm or less is considered satisfactory, a pH value lower than 8.0 will seldom give the desired result. At pH values lower than 7.0, the manganese content of the water is sometimes increased by solution of manganese from the sludge. It seems to make little difference whether lime or caustic soda is used to raise the pH value, although general experience in other tests indicates that lime is somewhat more preferable.

Effect of Age of Contact Material. Since it was suspected that the sludge might lose its power to remove iron and manganese after continued use, or through aging, a freshly made sludge was divided into two portions, one of which was used continuously for nearly two months and the other stored for 100 days before use.

In the experiment on continued use, the sludge received daily additions of iron-and-manganese bearing water which were then with-

TABLE 3.—EFFECT OF pH VALUE ON IRON AND MANGANESE REMOVAL BY ACTIVE SLUDGE. ALL EXPERIMENTS ON BROOKLINE WATER

Water	Adjusting Chemical	Final pH Value	Manganese		Iron	
			Initial	Final	Initial	Final
Brookline	H_2SO_4	6.7	0.75	0.90	1.60	0.08
Brookline	None	6.9	0.75	0.80	1.60	0.10
Brookline	$Ca(OH)_2$	7.4	0.75	0.13	1.60	0.10
Brookline	$Ca(OH)_2$	7.6	0.75	0.03	1.60	0.10
Brookline	$Ca(OH)_2$	9.1	0.75	0.04	1.60	0.02
Brookline	H_2SO_4	4.7	0.75	0.80	1.60	0.30
Brookline	H_2SO_4	5.9	0.75	0.80	1.60	0.30
Brookline	None	7.0	0.75	0.42	1.60	0.10
Brookline	$Ca(OH)_2$	9.1	0.75	0.03	1.60	0.10
Brookline	$Ca(OH)_2$	9.7	0.75	0.05	1.60	0.30
Brookline	$Ca(OH)_2$	10.0	0.75	0.04	1.60	0.20
Brookline	H_2SO_4	6.6	0.75	0.85	1.60	0.20
Brookline	H_2SO_4	6.9	0.75	0.65	1.60	0.16
Brookline	$Ca(OH)_2$	7.8	0.75	0.20	1.60	0.20
Brookline	$Ca(OH)_2$	8.5	0.75	0.23	1.60	0.32
Brookline	$Ca(OH)_2$	9.1	0.75	0.05	1.60	0.16
Brookline	$Ca(OH)_2$	7.4	0.30	0.20	1.20	0.16
Brookline	$Ca(OH)_2$	7.7	0.30	0.15	1.20	0.10
Brookline	$Ca(OH)_2$	7.7	0.30	0.12	1.20	0.12
Brookline	$Ca(OH)_2$	7.8	0.30	0.08	1.20	0.08
Brookline	$Ca(OH)_2$	8.0	0.30	0.03	1.20	0.10
Brookline	$Ca(OH)_2$	8.1	0.30	0.02	1.20	0.04
Brookline	$Ca(OH)_2$	8.4	0.30	0.01	1.20	0.02
Brookline	$Ca(OH)_2$	7.8	0.20	0.01	1.20	0.04
Brookline	$Ca(OH)_2$	8.2	0.20	0.01	1.20	0.04
Brookline	$Ca(OH)_2$	8.5	0.20	0.02	1.20	0.04
Brookline	$Ca(OH)_2$	8.2	0.20	0.03	1.20	0.06
Brookline	None	6.5	0.50	0.45	1.00	0.00
Brookline	NaOH	7.0	0.50	0.20	1.00	0.00
Brookline	NaOH	7.5	0.50	0.25	1.00	0.00
Brookline	NaOH	8.0	0.50	0.15	1.00	0.00
Brookline	NaOH	8.5	0.50	0.05	1.00	0.00
Brookline	NaOH	9.0	0.50	0.12	1.00	0.00
Brookline	NaOH	9.5	0.50	0.00	1.00	0.00
Brookline	$Ca(OH)_2$	7.0	0.50	0.15	1.00	0.00
Brookline	$Ca(OH)_2$	7.5	0.50	0.15	1.00	0.00
Brookline	$Ca(OH)_2$	8.0	0.50	0.00	1.00	0.00
Brookline	$Ca(OH)_2$	8.5	0.50	0.00	1.00	0.00
Brookline	$Ca(OH)_2$	9.0	0.50	0.00	1.00	0.00
Brookline	$Ca(OH)_2$	9.5	0.50	0.00	1.00	0.00

drawn and tested for iron and manganese after a suitable contact period. The sludge showed no decrease in activity with continued use. For example, after 21 cycles of use on Brookline water, it was still capable of reducing 1.0 ppm of iron to 0.12 ppm, and 0.2 ppm of manganese to 0.02 ppm at pH 8.0. Since these results were fully as good as those obtained when the sludge was fresh, it was concluded that continued use did not impair the powers of the sludge.

The sludge which was stored for 100 days also preserved its power to remove iron and manganese from Brookline water as shown by the data of Table 4. In these experiments the adjustment of the pH value was effected by lime.

TABLE 4.—REMOVAL OF IRON AND MANGANESE BY SLUDGE AFTER STORAGE FOR ONE HUNDRED DAYS

Water	Contact Time	Volume of Sludge ml.	Final pH	Manganese Initial	Manganese Final	Iron Initial	Iron Final
Brookline	10 min.	50	7.1	0.50	0.00	1.60	0.02
Brookline	10 min.	25	7.5	0.50	0.00	1.60	0.02
Brookline	10 min.	10	7.7	0.50	0.03	1.60	0.08
Brookline	10 min.	5	7.8	0.50	0.20	1.60	0.10
Brookline	10 min.	1	7.8	0.50	0.50	1.60	0.40
Brookline	10 min.	trace	7.8	0.50	0.50	1.60	0.60

Effect of Quantity of Sludge. The rapidity of the removal of iron and manganese from water by these active sludges tends to confirm Tillmans' theory that the process is primarily one of adsorption. If this is the case, then the quantity of sludge used in the process is of considerable significance, and it may also be expected that as the quantity of sludge per volume of water is decreased, the residual iron and manganese will become greater.

Table 5 contains the results of experiments on Brookline water in which the quantity of sludge used per liter of water was varied over a wide range. Similar results on other waters are given in Table 6. A contact period of 20 minutes was allowed before filtration in all experiments. Both tables show that a substantial amount of sludge, in terms of dry solids per liter of water, is required to reduce the residual iron and manganese to desirable levels. If a residual of 0.1

TABLE 5.—EFFECT OF QUANTITY OF SLUDGE ON REMOVAL OF IRON AND MANGANESE FROM BROOKLINE WATER

Quantity of Sludge		pH Value		Iron		Manganese		Removal ppm per g. solids	
ml.	g. solids per liter	Initial	Final	Initial	Final	Initial	Final	Iron	Manganese
30	0.72	—	8.0	1.10	0.10	0.48	0.005	1.39	0.66
20	0.48	—	7.9	1.10	0.16	0.48	0.01	1.96	0.98
15	0.36	—	7.9	1.10	0.50	0.48	0.03	1.67	1.25
8	0.19	—	7.7	1.10	0.30	0.48	0.04	4.16	2.29
3	0.07	—	7.6	1.10	0.40	0.48	0.15	9.72	4.58
trace	0.01	—	7.4	1.10	0.70	0.48	0.30	40.0	18.0
50	1.21	7.2	—	0.70	0.04	0.28	0.01	0.55	0.22
30	.72	7.2	—	0.70	0.08	0.28	0.02	0.86	0.36
20	.48	7.2	—	0.70	0.20	0.28	0.16	1.04	0.80
10	.24	7.2	—	0.70	0.30	0.28	0.17	1.67	0.46
5	.12	7.2	—	0.70	0.40	0.28	0.21	2.50	0.58
trace	.01	7.2	—	0.70	0.50	0.28	0.25	20.00	3.0
25	.61	9.6	—	0.70	0.08	0.28	0.01	1.12	0.46
15	.36	9.6	—	0.70	0.18	0.28	0.01	1.44	0.75
8	.19	9.6	—	0.70	0.14	0.28	0.01	2.95	1.42
3	.07	9.6	—	0.70	0.30	0.28	0.05	5.71	3.28
1	.024	9.6	—	0.70	0.36	0.28	0.11	14.1	7.08

ppm for both iron and manganese is considered satisfactory, the amount of sludge required seems to be of the order of 0.6 to 0.7 gram per liter, or 600 to 700 ppm of dry suspended solids. The process thus approaches the activated sludge process of sewage treatment in the amount of active material employed.

As the amount of sludge used is decreased, the water contains increasing residual concentrations of iron and manganese. If the amount of iron and manganese removed per unit of sludge solids is calculated, as in Table 6, it is found that this increases as the sludge concentration decreases. Both of these facts point to an adsorption mechanism as the dominant element in the removal process. An attempt has been made to analyze the results in terms of the Freundlich equation:

$$\frac{X}{M} = KC^{\frac{1}{n}}$$

in which X=amount of iron or manganese adsorbed.

M=weight of sludge solids employed.
C=concentration of iron or manganese remaining in the water.
K and n=constants.

Although a few of the experiments showed reasonable conformance to this equation, the agreement was not particularly good in most of them. It is therefore concluded that processes other than adsorption play a part in the removal of iron and manganese.

Further evidence confirming this conclusion was obtained from experiments conducted at 37° C. rather than at room temperature. The experiments were made on Methuen water and the results are included in Table 6. In these, the residual iron and manganese concentrations are lower than those for corresponding experiments at room temperature. Similar results were obtained by Tillmans and his co-workers. If adsorption were the only factor involved, the residual iron and manganese concentrations would be greater at the higher temperatures, since adsorption becomes less effective as the temperature increases.

Action of Sludges on Various Types of Water. The bulk of the experimental work was done with the Brookline, Mass., raw water, since this was most easily secured in quantity. However, as previously noted, three other iron-and-manganese bearing waters were also used, in order to determine whether the effectiveness of the sludges was dependent on the nature of the water. The results of parallel experiments on raw waters from Methuen, Lowell, and Cohasset are given in Table 6. These results show that the sludges are capable of reducing iron and manganese to satisfactory levels in all waters so far tried, provided that a sufficient amount of sludge is added and the pH value is properly adjusted. Attention is called to the Methuen water, in which an initial manganese content of 5 ppm was reduced to between 0.03 and 0.02 ppm by a 20-minute contact. Manganese is generally considered to be more difficult to remove than iron by the methods now used in practice. However, in all experiments with the active sludges this does not seem to be true.

Practical Application. The authors believe that sufficient evidence has been presented to show that if some means could be devised to use for the practical removal of iron and manganese from water

TABLE 6.—ACTION OF SLUDGES ON WATERS OF VARIOUS TYPES

Water	Sludge Solids g. per liter	pH Value Initial	pH Value Final	Iron Initial	Iron Final	Manganese Initial	Manganese Final
Methuen	Raw Water	7.8	—	0.10	—	5.0	—
Methuen	1.21	—	8.6	0.10	0.10	5.0	0.03
Methuen	0.72	—	8.4	0.10	0.08	5.0	0.20
Methuen	0.48	—	8.3	0.10	0.10	5.0	0.50
Methuen	0.24	—	8.3	0.10	0.06	5.0	2.50
Methuen	0.12	—	8.3	0.10	0.04	5.0	1.50
Methuen	0.01	—	8.1	0.10	0.00	5.0	4.50
Methuen	1.21	—	8.2	0.10	0.16	5.0	0.02
Methuen	.72	—	8.3	0.10	0.20	5.0	0.25
Methuen	.48	—	8.4	0.10	0.06	5.0	0.50
Methuen	.24	—	8.5	0.10	0.06	5.0	1.20
Methuen	.12	—	8.9	0.10	0.16	5.0	2.50
Methuen	.01	—	9.0	0.10	0.00	5.0	3.50
Methuen, 37° C.	.72	—	8.6	0.10	—	5.0	0.18
Methuen, 37° C.	.48	—	8.7	0.10	0.04	5.0	0.44
Methuen, 37° C.	.24	—	8.7	0.10	0.04	5.0	1.00
Lowell	Raw Water	7.2	—	1.60	—	1.55	—
Lowell	1.21	7.2	—	1.60	0.00	1.55	0.02
Lowell	.72	7.2	—	1.60	0.05	1.55	0.11
Lowell	.48	7.2	—	1.80	0.14	1.55	0.29
Lowell	.24	7.2	—	1.80	0.16	1.55	1.00
Lowell	.12	7.2	—	1.80	0.30	1.55	0.90
Lowell	1.21	10.0	—	1.80	0.12	.60	0.02
Lowell	.48	10.0	—	1.80	0.20	.60	0.05
Lowell	.12	10.0	—	1.80	1.00	.60	0.25
Cohasset	Raw Water	6.6	—	3.00	—	0.20	—
Cohasset	1.21	6.6	—	3.00	0.30	0.20	0.02
Cohasset	.72	6.6	—	3.00	0.08	0.20	0.06
Cohasset	.48	6.6	—	3.00	0.10	0.20	0.15
Cohasset	.24	6.6	—	3.00	0.30	0.20	0.60
Cohasset	.12	6.6	—	3.00	0.70	0.20	0.05
Cohasset	.05	6.6	—	3.00	1.20	0.20	0.22
Cohasset	1.21	9.8	—	3.00	0.22	0.20	0.00
Cohasset	.72	9.8	—	3.00	0.10	0.20	0.01
Cohasset	.48	9.8	—	3.00	0.16	0.20	0.02
Cohasset	.24	9.8	—	3.00	0.30	0.20	0.02
Cohasset	.12	9.8	—	3.00	0.70	0.20	0.12
Cohasset	.05	9.8	—	3.00	0.80	0.20	0.13

supplies active materials of the type described in this paper, this removal could be effected with less elaborate and costly structures than those now employed. A contact period of no more than 20 or 30 minutes is indicated as the maximum necessary. Present installations call for much longer contact periods and extensive sedimentation facilities. If the conclusions drawn by the writers are correct, the removal of iron and manganese could be effected by a "sludge-blanket" type of flocculation tank with a short detention period, followed by a rapid sand filter.

Attempts to duplicate this sort of treatment in small-scale laboratory equipment have indicated that certain difficulties are involved that might or might not exist in a full-sized plant. In the model apparatus, good results were obtained at first, but the sludges subsequently became dispersed and passed through the filters, producing cloudy effluents. This may have been due to the high internal velocities obtaining in the models or to an inherent lack of durability in the sludge flocs. Pilot plant experiments on a moderate scale would soon demonstrate whether or not the floc could be made sufficiently durable to withstand the velocities involved in a practical installation.

The operation of a plant of the type visualized would involve the control of the pH value in the flocculating tank to produce optimum results and also the control of the concentration and condition of the sludge solids in this tank. Although this admittedly offers more difficulty than the operation of a coke-bed, sedimentation, and slow sand filter installation, it may be justified by the saving in space and equipment.

Theoretical Considerations. Although the experimental work was not primarily directed toward an investigation of the theory of iron and manganese removal, certain conclusions may be drawn from it. It is evident that active masses of ferric and manganic hydrates are capable of removing iron and manganese from solution at a relatively rapid rate. There is a very definite distinction between the removal of iron and that of manganese, which is most clearly shown in the optimum pH ranges for the two metals. The best removals of iron were obtained at pH values from 7.0 to 9.0; for manganese the optimum range was 8.5 to 10.0. Consequently, the removal of manganese required that the waters be treated with some alkaline agent such as lime or soda ash.

If Tillmans' theory that manganese is adsorbed by the active surfaces of manganic hydrate with the release of hydrogen ions is correct, then the function of the alkaline reagent is to accelerate the process by removing the hydrogen ions liberated. The adsorption of manganese must be of the pseudo type, since the adsorbed ions must be subsequently oxidized to manganic hydrate. This may explain why the Freundlich equation fails to hold, and why the removal of manganese is more, rather than less, complete at higher temperatures. The mechanism by which the adsorbed manganese is oxidized is of some interest. One experiment was performed in which iron and manganese were removed by an active sludge in the absence of oxygen, but the work was not carried far enough to demonstrate that this could be continued indefinitely. It would be of considerable interest to study the effect of continued anaerobic conditions on the power of these contact materials to remove iron and manganese.

The experiments performed have raised in the minds of the authors many questions that must await the opportunity for further research. For example, does the ferric hydrate in the sludges perform any useful function, or is all the work done by the manganic hydrate? Is the mechanism of iron removal similar to that of manganese, or is the iron precipitated directly without being adsorbed on the sludges? Moreover, because of the necessity for filtration, it is not yet determined just how rapidly these sludges can remove iron and manganese; we only know that a 15-minute contact is often sufficient.

Summary and Conclusions. Laboratory experiments have been performed on the action of prepared suspensions of ferric and manganic hydrates in removing iron and manganese from several waters. The following conclusions may be drawn from these experiments:

1. Suspensions of the hydrates made from ferrous sulfate and potassium permanganate are capable of removing iron and manganese from all waters tested, provided that the pH value of the mixture is properly adjusted. Residual iron and manganese concentrations may be reduced by these sludges to values that would be acceptable in water treatment practice.

2. The action of the sludges is rapid, requiring not more than 15 to 30 minutes for its completion.

3. The optimum range of pH values for removal of iron is 7.0

to 9.0; for removal of manganese, from 8.5 to 10.0. Any alkaline reagent may be used to correct the pH value.

4. The activity of the sludges is not affected either by storage or continued use.

5. The concentration of sludge required for satisfactory removal of iron and manganese is of the order of 600 to 700 ppm of dry suspended solids.

6. There are sufficient indications of economy in construction cost and space required to warrant consideration of the use of active sludges for iron and manganese removal, but pilot-plant experiments are needed before it can be definitely decided whether or not the process has a practical value.

REFERENCES

1. Weston, R. S. The Purification of Ground Waters Containing Iron and Manganese. Trans. A.S.C.E., **64**, 112 (1909).
2. Weston, R. S. Some Recent Experiences in the Deferrization and Demanganization of Water. J. New Eng. Water Works Ass'n., **28**, 27 (1914).
3. Kirchoffer, W. E. The Use of Beds of Manganese Ore in Iron and Manganese Removal. J. Am. Water Works Ass'n., **28**, 1488 (1936).
4. Hale, Frank E. Iron Removal Without Aeration—the Precipitation of Ferrous Carbonate in a Closed System. J. Am. Water Works Ass'n., **28**, 1577 (1936).
5. Naumann, E. Iron Removal Through Addition of Iron. Gas u. Wasserfach, **82**, 151 (1939).
6. Nelson, G. H., Levine, M., and Lynch, D. J. F. Removal of Iron by Lignin in Water Treatment. Paper Trade J. **108** (1939) TAPPI Sect. 117.
7. Zapffe, Carl. History of Manganese in Water Supplies and Methods for Its Removal. J. Am. Water Works Ass'n., **25**, 655 (1933).
8. Tillmans, J., Hirsch, Paul, and Höffner, Fritz. Adsorption of Divalent Manganese by Manganese Dioxide. Gas u. Wasserfach, **70**, 25 (1927).
9. Tillmans, J., Hirsch, Paul, and Grohmann, H. Further Experiments on the Adsorbing Power of Manganese Dioxide. Gas u. Wasserfach, **71**, 481 (1928).
10. Tillmans, J., Hirsch, Paul, and Grohmann, H. How Does Oxidation of Divalent Manganese Occur? Gas u. Wasserfach, **71**, 515 (1928).

ROCKPORT, MASS.—THE EVOLUTION OF A SMALL WATER WORKS SYSTEM

BY E. SHERMAN CHASE* AND GEORGE C. HOUSER†

[*Received September 24, 1942.*]

The story of the Rockport water works illustrates well the problems and vicissitudes encountered in the development and operation of small water supplies. How such problems were met at Rockport and the presentation of factual data, rather than a mere historical narrative, constitute the objectives of this paper.

General. Rockport, situated at the tip end of Cape Ann about 30 miles north of Boston, is one of the most popular summer resorts in Massachusetts. As a result of this popularity, the normal resident population of about 3,600 is greatly increased during July and August, sometimes reaching week-end peaks estimated at 11,000. This extreme variation in population results in one of the serious problems confronting the water department, namely the supplying of enough water to meet the needs of the large summer population at a time when normal demands are greatest.

The water supply of Rockport is derived in part from Cape Pond, a natural pond storing substantially all the runoff from a small drainage area. A second source of supply consists of driven wells in the valley of Mill Brook.

Historical. The water works were built and put into service late in 1894. Before the pond was taken as a source of supply, the Massachusetts State Board of Health pointed out the desirability of filtering the water, due to the probability of tastes and odors from microorganisms. Filtration was not adopted, however, and over the years considerable trouble was experienced with objectionable tastes and odors, particularly during the summer, much to the annoyance of the summer visitors.

Various investigations of the supply were made from time to time by the State Department of Public Health, and in each instance the

*Partner, Metcalf & Eddy, Engineers, Boston, Mass.
†Assistant Engineer, Metcalf & Eddy.

desirability of filtration was pointed out by the Department. Rules and regulations for the sanitary protection of Cape Pond were established by the Health Department on August 7, 1902. Reports on the pond supply were made also by H. W. Spooner, Consulting Engineer of Gloucester, and by the late Henry A. Symonds, Consulting Engineer of Boston and former editor of the JOURNAL, in 1903 and 1919, respectively. Both reports recommended filtration, but no action upon these recommendations of the consulting engineers nor upon those of the Health Department was taken.

In 1921, Metcalf & Eddy made another investigation, and again filtration was recommended. Copper sulfate treatment, based upon regular microscopic examinations of the supply, was recommended for control of algae. This latter recommendation was adopted, and copper sulfate treatment of Cape Pond has been carried out whenever analyses indicated such treatment to be advisable. This procedure produced reasonably satisfactory results but was not sufficiently effective to obviate all complaints, particularly those by summer residents. Eventually, the town voted to install a filter plant, which was completed and put into operation in the summer of 1939.

As the safe yield of Cape Pond approximated the average water consumption of the town, it was decided, in 1925, to supplement the pond supply in summer by the development of a ground-water supply in the Mill Brook Valley. This development was completed in 1926 and used as an auxiliary source during the summer only until 1939. In 1938, an extension of the well field was started and the new development was carried out in such a manner as to permit all-year use of the supply. The new work was completed in 1939.

The original standpipe is located on Great Hill, rising from the northerly end of Cape Pond. In 1932, a second standpipe was erected on Pigeon Hill, to improve pressures throughout the distribution system and to increase storage to meet peak demands during the summer. Each standpipe has a capacity of 300,000 gal.

Over the years, purchases have been made of land surrounding Cape Pond, so that at present the town owns all the land bordering the pond, except for that occupied by two ice-houses. Other minor improvements in connection with the sources of supply have been made from time to time.

Water Consumption. The water supply problem is rendered particularly difficult as a result of the extreme seasonal variation in population, as previously mentioned. The normal resident population has decreased for the past 45 years from 5,289 in 1895 to 3,556 in 1940, but the summer population during the months of July and August has tended to increase. This increase has been accompanied by a greater demand for water during the critical months of low yield, with the result that curtailment of use of water has been necessary during dry summers.

The average annual use of water for the past 19 years has been 0.353 m.g.d.; for the last year of record (1941) it was 0.374 m.g.d. The corresponding seasonal use is reflected in the figures of monthly use shown in Table 1.

TABLE 1—AVERAGE DAILY WATER CONSUMPTION (M.G.D.) OF ROCKPORT, MASS.

	1923-1941	1941		1923-1941	1941
Jan.	0.261	0.211	July	0.586	0.700
Feb.	0.268	0.224	Aug.	0.560	0.599
Mar.	0.266	0.221	Sep.	0.422	0.533
Apr.	0.264	0.278	Oct.	0.317	0.322
May	0.319	0.340	Nov.	0.252	0.221
June	0.463	0.594	Dec.	0.251	0.227

These values show clearly the high consumption that occurs during the summer. Figures for 1941 include wash water used at the filter plant.

Yield of Cape Pond. The yield of Cape Pond has averaged very nearly the same as the water consumption. In fact, during nine out of the past nineteen years, the yield has been less than the demand of the town. Table 2 shows the yearly consumption of Cape Pond water and the pond yields for a period of 19 years. In computing these yields, it has been necessary to neglect the small amounts of water lost through Alewife Brook at times of high water in the spring. The error introduced in this manner is not large, because the overflow level is reached or exceeded only infrequently and for short periods of time. This table shows how close Rockport has been to a water famine. Had it not been for the auxiliary well supply, the actual deficiency would have been materially greater.

TABLE 2—COMPARISON OF WATER CONSUMPTION AND YIELD OF CAPE POND BY YEARS, IN MILLION GALLONS.

Year	Yield	Consumption	*Excess* or *Deficiency* of Yield	
1923	107	134	—	27
1924	121	104	17	—
1925	119	107	12	—
1926	94	100	—	6
1927	122	95	27	—
1928	81	96	—	15
1929	70	116	—	46
1930	114	120	—	6
1931	141	112	29	—
1932	152	139	13	—
1933	146	123	23	—
1934	120	143	—	23
1935	111	134	—	23
1936	146	116	30	—
1937	131	131	0	0
1938	155	153	2	—
1939	88	142*	—	54
1940	134	91*	43	—
1941	49	89*	—	40
Average	116	118	—	2

*Including wash water used at filter plant.

CAPE POND SUPPLY

Cape Pond occupies a narrow valley, the easterly and westerly slopes of which rise rather sharply from the pond to elevations about 100 ft. above the water level. At the northerly end of the pond there is an area of low, swampy land of about 10 acres which has been partly ditched in recent years. At the extreme southerly end of the pond a low divide prevents the water from having an outlet to the sea, through a continuation of the valley. The existing outlet, through a swampy area at the western shore of the pond, forms the origin of Alewife Brook, which is tributary to one of the reservoirs of the city of Gloucester.

The high-water mark of Cape Pond is about 72.4 ft. above mean tide. The pond is approximately 3200 ft. long and has an average width of about 600 ft. It is a "Great Pond", and the right to take water from it was granted to the town by the Commonwealth. The water level varies from year to year, the maximum difference approximating 6 ft. High water usually occurs in the spring and low water in the late summer and fall.

The pond has a total storage capacity of 195 m.g. at ordinary high water and a watershed area of 0.42 sq. miles, or 267 acres, of which 43 acres are pond area. The maximum available storage capacity is estimated to be about 177 m.g., and the safe yield about 0.25 m.g.d.

Geology of Drainage Area. The island of Cape Ann is composed of three classes of material, namely bed rock of hornblendic granite, igneous dike rock, and glacial drift deposits. The watershed of Cape Pond consists mainly of drift deposits with a small amount of granite ledge outcropping on the hill on which the standpipe is situated. Many large boulders occur upon the easterly side of this hill and at the northerly end of the pond. The drift deposits are of fairly porous materials and also contain many boulders. In view of the small surface drainage area, it seems probable that the pond is largely spring-fed from ground water collected in and percolating through the glacial drift. The greater portion of the watershed is of little agricultural value. Most of the area is covered with underbrush, scrub pines and deciduous trees.

Population on Watershed and Pollution Hazards. There are but a few permanently occupied houses located upon the watershed. One of these houses is that of the Superintendent and the others are located on the east side of the Gloucester-Rockport highway, practically on the watershed divide. A fish-glue factory, formerly in use, has been abandoned, as have two cottages at one time located on the southern shore of the pond.

On the whole, the sanitary conditions around the pond and on the watershed are good. Purchase of the shores of the pond has given the water commissioners control over its use. Ice-harvesting, which is permitted under supervision, brings a number of temporary laborers to the pond during cutting operations and during the loading of ice-trucks in summer. No fishing is now allowed, and the number of casual visitors to the pond is not large. There is, however, some danger of accidental or wilful contamination of the pond by such visitors as do have access to it.

Probably one of the more serious sources of pollution is the large number of sea-gulls that frequent the pond. Both Rockport and Gloucester discharge untreated sewage into the sea, and gulls coming to the pond from the sewage-polluted areas may well transfer pollu-

tional organisms to the pond waters. This hazard has been described in some detail in a paper published previously in this JOURNAL.[1] Because of the potential dangers to the supply, chlorination was begun December 28, 1923, and has been continued since.

Tastes, Odors, and Color. In the past, the principal complaints relative to the supply have been in connection with disagreeable tastes, odors, and discoloration. The water leaching through the swamp at the northern end of the pond dissolves considerable amounts of organic matter, which provides food for the microörganisms that thrive in the pond. The growth, death, and subsequent disintegration of these organisms result at times in disagreeable tastes and odors in the pond water as pumped.

The types of microörganisms vary in different seasons and years. Prior to systematic treatment with copper sulfate it was generally true that one kind predominated, then disappeared, to be followed by another. With control of the organic life in the pond by copper sulfate, there has been a somewhat greater uniformity of both numbers and types of organisms. In general, the predominating organisms are diatoms, usually *Asterionella, Synedra* and *Tabellaria.* Other types occur less frequently, although *Dinobryon* is quite common during the colder months. *Anabaena* of the blue-green group has also been of fairly frequent occurrence.

Copper Sulfate Treatment. The quantity of copper sulfate applied to Cape Pond, together with the results obtained by such treatment, from May, 1922, to August, 1934, has been set forth in a paper previously published in this JOURNAL.[2] Corresponding data for the years 1934 to 1941, inclusive, are presented in Table 3.

In the 20-year period during which Cape Pond has been treated with copper sulfate, the quantity of chemical applied to the pond at each treatment has varied from 425 to 1,100 lb. and the dosage has varied from 2.3 to 6.1 lb. per m.g. The rate most frequently employed was approximately 6 lb. per m.g. or 0.7 p.p.m. From one to four treatments were administered to the pond each year, the total quantity applied ranging from 838 to 3,400 lb. per year. The cost of treatment, exclusive of engineering services and analyses, averaged 5.8¢ per lb. of copper sulfate applied in 1934 and 5.9¢ in 1935.

[1]Houser, G. C. This Journal, **45**, 1, 15, March, 1931.
[2]Houser, G. C., this Journal, **49**, 2, 156, June, 1935.

TABLE 3—RESULTS OF COPPER SULFATE TREATMENT, AS SHOWN BY NUMBERS OF MICROSCOPIC ORGANISMS PRESENT IN CAPE POND WATER, 1934-1941.

Date of treatment	Rate of application of copper sulfate (p.p.m.)	Total microscopic organisms* (standard units per ml.)		Reduction in total organisms (%)	Time of collection of samples	
		Before treatment	After treatment		No. of days before treatment	No. of days after treatment
May 21, 1934	0.7	1,360	323	76	5	16
Aug. 16, 1934	0.7	1,880	1,950	Increase	3	13
Nov. 9, 1934	0.7	3,540	1,390	61	4	10
June 14, 1935	0.5	4,885	2,330	52	3	11
Oct. 2, 1935	0.7	7,525	918	88	2	19
April 27, 1936	0.7	1,239	1,030	17	6	15
June 22, 1936	0.7	1,325	1,100	17	6	14
Aug. 26, 1936	0.6	3,990	2,870	28	7	13
April 29, 1937	0.7	10,860	4,610	58	3	12
June 29, 1937	0.7	3,380	370	89	8	13
Sept. 1, 1937	0.5	8,800	11,930	Increase	2	19
Sept. 29, 1937	0.6	11,930	10,220	14	9	19
July 14, 1938	0.7	3,775	350	90	3	11
Aug. 29, 1938	0.6	2,550	10,000+	Increase	4	15
Sept. 16, 1938	0.7	485	370	24	0**	7
April 30, 1939	0.7	26,000	2,430	91	10	10
Aug. 14, 1939	0.7	255	505	Increase	7	14
June 14, 1940	0.7	4,750	4,305	9	4	12
May 19, 1941	0.5	2,530	730	71	5	23
Sept. 8, 1941	0.6	4,340	1,070	75	5	11
Oct. 20, 1941	0.7	2,600	4,320	Increase	6	14
Nov. 28, 1941	0.7	8,450	5,685	33	2	12

*When more than one sample was collected on any one day, the figure given is the average for all samples. Examinations made by the Massachusetts Department of Public Health and Metcalf & Eddy, 1934-1936. Examinations made by Metcalf & Eddy, 1937-1941.

**"0" indicates that sample was collected on day of treatment, just before treatment was begun.

During the past 20 years Cape Pond received 52 doses of copper sulfate. On 28 of these occasions, reductions of 50 per cent or more in the number of microscopic organisms in the pond water were effected, some of the reductions running as high as 96 per cent. Sixteen applications brought about reductions of 9 to 49 per cent. On the remaining eight occasions there was an actual increase in number of organisms present in the pond water, in spite of the copper sulfate treatment.

Red Water. At times, complaints have been received of rusty water flowing from the taps. Flushing of the mains was formerly not as regular nor as systematic as in recent years. It is now the practice to flush the mains thoroughly twice a year, once in the late spring and again in the fall. Flushing is begun by opening hydrants in the center of town and progressively working towards the outskirts.

Physical and Chemical Quality of Pond Water. The results of analyses show the turbidity of the pond water to vary from "very slight" to "distinct" and sediment to be present in amounts from "very slight" to "considerable." The color at times is distinctly high, as is the organic residue, due to the effect of the swamp at the head of the pond and to the decomposition of muck accumulated in the bottom of the pond over many years. Figures for free and albuminoid nitrogen also are high, due to these sources of organic matter. Chlorides are high because of the proximity to the sea. The hardness of the pond water is relatively low. Bacterial analyses usually show little or no evidence of active contamination. At times, however, coliform organisms are present in 10-ml. inoculations, probably the result of contamination by gulls.

Mill Brook Supply

The development of a ground-water supply in the Mill Brook valley began with the putting down of test wells in the fall of 1924. As a result of this investigational work, it was concluded that a gang of tubular wells would provide enough water of excellent quality to augment the regular Cape Pond supply during dry seasons for some time to come. The estimated yield was 150,000 g.p.d. In 1926, four 2½-in. tubular wells, driven to a depth of about 25 ft. into sand and gravel, were connected to a gasoline-driven, triplex plunger pump, which discharged through 1440 ft. of 4-in. Universal cast-iron pipe to the 10-in. main in the highway, leading from the Great Hill standpipe to the village. Inasmuch as the well supply was installed for summer use only, the discharge main was laid on the surface of the ground and drained at the end of the season. The pumping equipment was housed in an inexpensive, ready-built steel garage.

The years 1929 and 1930 were characterized by low rainfall and, in order to permit the drawing of more water from the Mill Brook

valley, four more tubular wells were added in 1930. The drought of 1929-1930 brought Cape Pond to a lower level than at any other time in the history of the water works. This caused serious consideration of placing the Mill Brook supply on a year-round basis, but it was not until 1937 that the decision was reached to make a permanent ground-water development in the Mill Brook valley.

In 1938, more tubular wells were put down, and an extended pumping test was carried out upon the new and old wells. The data obtained were used to determine the probable yield of the new well field and the capacity of new pumping equipment. Including the old wells, twenty-three wells were connected to a common cast-iron suction header, which in turn was connected to pumping equipment housed in a new station. A new force main was also laid across country to Railroad Avenue, where connection was made to an existing 8-in. line. The new work was completed and was put into operation in April, 1939.

Yield of Wells. The surface drainage area above the well field is 0.4 sq. miles. To the west of the well field, there is an extensive overburden of glacial origin, of irregular topography and without any well-defined drainage course. It is probably true that the yield of the wells is augmented by ground water from this area to the west, lying beyond the superficial catchment above the wells. Table 4 gives the estimated yields of the present well development.

TABLE 4—PROBABLE SAFE YIELDS OF MILL BROOK WELL FIELD IN GALLONS PER DAY

	Minimum	Maximum	Average
Very dry year	150,000	250,000	200,000
Very wet year	250,000	350,000	300,000
Average year	200,000	300,000	250,000

From Tables 2 and 4, it will be seen that the yearly average safe supply for Rockport, from both Cape Pond and the Mill Brook wells, may vary from 400,000 to 600,000 g.p.d. Summer peak demands are in excess of these figures but are met by drawing on the storage of Cape Pond.

Quality of Well Water. The water pumped from the wells is clear, practically colorless, odorless, and rather soft. The content of nitrogen in its various forms is low and indicates the absence of any material amount of organic matter. The chloride content is high, due

to the proximity of the ocean. The bacterial quality of the water is excellent, showing very small numbers of bacteria and generally none of the coli-aerogenes group. Since the content of free carbon dioxide is moderately high and the hydrogen-ion concentration is low, the well water has slightly corrosive qualities. On the other hand, the iron content is very low. On the whole, the water is of excellent sanitary quality and its physical characteristics render it an unusually satisfactory drinking water.

Recent Improvements

In 1937, the town decided to increase the available water supply by making a permanent ground-water development in the Mill Brook Valley and to build a water filtration plant for the Cape Pond supply. In 1939, construction was begun on a dike at Cape Pond, to conserve water formerly wasted at the outlet. This dike was completed in November, 1941. The initial step in the improvements to the water supply consisted in the enlargement of the Mill Brook Valley development and the construction of a permanent, automatic, pumping station for year-round operation.

Mill Brook Valley Wells and Connections. Fifteen new 2½-in. wells were driven in Mill Brook Valley in 1938, making a total of 23 in that area. The wells are all of 2½-in., genuine wrought-iron pipe, of the open-end type, equipped with a perforated pipe section, 48 in. long, at the bottom. The average depth of the wells is about 26 ft. For the most part, they were driven through fine sand and gravel, with a little clay. The surface cover of the well field is a fairly thick layer of loam.

The wells are connected to a common, cast-iron, suction header of varying size, which leads to the pumping station. Individual well connections to the suction header are 2½ in. in size. Eight of the connections are made up with cement-lined, wrought-iron pipes with Dresser couplings. Each of the other connections includes a short, flexible, lead gooseneck at the well riser, a gate valve and a length of 2½-in., cement-lined, wrought-iron pipe. The suction header consists of cement-lined, cast-iron pipe, which varies in size from 4 in. to 8 in. There is a minimum cover of 4 ft. over all suction piping, and all lines are pitched so as to give complete drainage back into the wells whenever desired.

Mill Brook Valley Pumping Station. The Mill Brook Valley pumping station is a one-story, concrete and granite structure, containing two rooms: a pump room, 29 ft. by 17 ft. in plan, and a chemical room, located in a wing, 13 ft. by 15 ft. in plan. All construction below ground level is of reinforced concrete. The superstructure is faced with native, Rockport, seam-face granite, with interior finish of walls and partitions of cinder blocks. Granite and cinder-block walls were carried up independently and made solid with concrete. A typical wall section is 18 in. thick, being composed of 4 in. of cinder block, 6 in. of concrete and 8 in. of outside granite. The roof is pitched and covered with slate.

The main equipment of the pumping station consists of three pumping units, a vacuum priming system and facilities for chemical treatment. The pumping units are Gardner-Denver centrifugal pumps. One is for summer or dry-weather operation and has a capacity of 140 g.p.m. against a total dynamic head of 250 ft. This pump is single-stage, with direct-connected, squirrel-cage, induction motor, and operates normally at a speed of 3,460 r.p.m. Another pump, also with direct-connected, high-speed, electric drive, takes care of maximum demand. It has a capacity of 240 g.p.m. against a total dynamic head of 220 ft. The third unit, being for emergency use, is driven by a gasoline engine. It is a two-stage pump, with a capacity of 240 g.p.m. at a head of 220 ft. Motive power is supplied by a 50-hp. Buffalo gasoline engine, operating normally at 1,800 r.p.m.

Two small Nash vacuum pumps are installed for automatic priming of the main pumps. One of these units has a 2-hp., single-cylinder, gasoline engine available for emergency use. A vacuum and sand-catcher tank in the suction piping acts as a sand-settling basin and is used in conjunction with the vacuum priming system. This tank is 10 ft. high and 5 ft. in diameter and is provided with inside baffles. The two priming units are of different sizes. One is driven by a 1-hp. electric motor and has a capacity of 11 c.f.m. at 10 in. of mercury vacuum, when operating at 1,750 r.p.m. The other has a 1½-hp. motor with a capacity of 15 c.f.m. at 10-in. vacuum and 1,750 r.p.m.

To furnish lime for pH correction, to reduce corrosiveness, a pulsating-type, electro-magnetic, Syntron chemical feeder is installed in the chemical room. It has a feed capacity of 10 lb. per hr. During

pumping, hydrated lime is automatically added to the water at the rate of about 160 lb. per m.g. This neutralizes the carbon dioxide, reduces corrosiveness and increases the hardness to about 50 p.p.m.

A Venturi meter is installed in the force main just outside the station, with a recording flow meter located inside. Drainage of the interior of the station is accomplished by means of a small, automatically operated, sump pump. The entire station can be and ordinarily is operated automatically and without continuous attendance. A 6-in., cement-lined, cast-iron force main extends from the pumping station across country in a northeasterly direction to Railroad Avenue where it is connected to an 8-in. main. The force main, 1916 ft. in length, was constructed by W.P.A. labor.

Cost of Mill Brook Valley Development. The following is a summary of costs of the Mill Brook Valley development carried out in 1938-39, including engineering, supervision and administration:

Wells (excluding 8 old wells)	$ 4,447.07
Connections	4,636.25
Mill Brook Valley pumping station	23,928.15
Force main (excluding W.P.A. labor)	3,320.44
Total	$36,331.91
Received from P.W.A.	9,898.80
Net cost to town of Rockport	$26,433.11

Filtration Plant. Construction was commenced in 1938 and finished in 1939 on a water filtration plant for the Cape Pond supply. The design of the filter plant was such as to utilize, in so far as possible, existing structures and equipment. Raw water is taken through a 12-in. intake, located in about 25 ft. of water, and is pumped to the filter plant. The original pumping equipment consisted of two Deane, tandem, compound-condensing steam pumps, with rated capacities of 1 m.g.d. each. In 1942, these steam pumps were replaced by motor-driven centrifugal pumps.

Prior to the construction of the filter plant, the water was pumped directly into the distribution system against the head maintained by two standpipes floating on the system. The pumping station at the

pond was continued in use as a low-lift station, to supply raw water to the filter plant. The chlorination equipment also was continued in use, for chlorinating the raw water before it was pumped to the filter plant, but recently this equipment has been placed at the filter plant to chlorinate the filtered water.

The capacity of the filter plant on the basis of 24-hour operation is 1 m.g.d. The essential features of the plant include an aerated mixing tank, three chemical-feed machines, a coagulation tank with mechanical mixing paddle, a sedimentation tank, two filter beds with capacities of 0.5 m.g.d. each, a clear-water reservoir and two, 1-m.g.d., high-lift, electrically operated, centrifugal pumps. The plant includes a small office and laboratory in which simple routine tests can be performed. A view of the plant is shown in Figure 1.

FIG. 1.—ROCKPORT, MASS. GREAT HILL FILTER PLANT AND STANDPIPE.

Aerated Mixing Tank. The aerated mixing tank serves two purposes: (1) the mixing of chemicals with the raw water and (2) aeration of the water for odor removal. The tank is 4 ft. wide by 11 ft. long, with an effective depth of 11.75 ft. The detention period is 5.6 minutes at the rated capacity of the plant. At the bottom of the tank, eight Carborundum diffuser plates are set in one long plate-holder, 1.5 ft. wide and 9.5 ft. long. Air is supplied by a small air compressor at a maximum rate of about 24 c.f.m. Raw water from the pond enters

the mixing tank about 3 ft. below the water surface, while chemicals are discharged into the water through hose feeders at the surface.

Chemical Feeding and Storage. Chemicals are fed by three Syntron chemical feeders of the pulsating, electro-magnetic type. The machines have capacities variable between 0.5 and 100 lb. per hour. Ordinarily, sulfate of alumina and activated carbon are used, as well as either hydrated lime or soda ash. The sulfate of alumina and activated carbon are discharged into the mixing tank, but the machine feeding lime or soda ash is arranged to discharge into the filtered-water lines, in order to permit control of the pH of the filtered water pumped to the distribution system.

Each feeder is supplied by means of a separate charging hopper with a capacity of 10 cu. ft., the opening of which is in the chemical-storage room on the second floor of the filter building. Here several months' storage capacity is available, the storage space for chemicals being 23 ft. 7 in. by 16 ft. 9 in. in plan. Chemicals are raised from the service entrance in the basement by means of a hoist.

Coagulation Tank. The water, after aeration and the addition of coagulating chemicals and activated carbon, flows into the coagulation tank, which is 11 ft. square, with an effective depth of 12.3 ft. This tank provides a detention period of 16 minutes at the normal rate of operation. A mechanical stirrer, consisting of four wooden paddles mounted on a vertical shaft, is located above the middle of the tank. The paddles have a horizontal spread of 7 ft. and a vertical spread of 8 ft., each plate being set at an inclination of 60 deg. with the horizontal. The speed of the driving mechanism can be varied from 0.5 to 2.0 r.p.m.

Sedimentation Tank. From the coagulation tank, the treated water flows through a 12-in. cast-iron pipe into the sedimentation tank through 12-in. inlets. This tank is a covered, reinforced-concrete structure, 30 ft. by 53 ft. in plan, with an effective depth of 14.5 ft. and a capacity of 23,100 cu. ft. The tank has a wooden longitudinal baffle along its center and discharges over a weir into a channel, from which the water passes onto the filters. The detention period afforded by the sedimentation tank is 4.2 hours at a rate of 1 m.g.d.

The base of the tank is sloped toward two drainage gates. All waste or drainage lines at the plant discharge into a common 18-in.

drain, which empties into a swampy area at the northerly end of Cape Pond. The roof of the sedimentation tank is equipped with observation and entrance manholes.

Filter Beds. There are two filter beds with filtering areas of 175 sq. ft. each. The capacity of each bed is 0.5 m.g.d. at a filtering rate of 125 m.g.d. per acre. The sand area of each bed is 12 ft. 8 in. by 13 ft. 10 in., with a sand depth of 30 in. The sand, which came from Provincetown, has an effective size of 0.42 mm. and a uniformity coefficient of 1.38. Below the sand is an 18-in. layer of graded gravel over the underdrains. The gravel varies in size from ¼-in. at the top to 2½-in. at the bottom. Settled water flows over the top of the filter beds from a side channel.

The underdrainage system consists of a central manifold of 24 cast-iron tees, discharging into a box channel. To these tees are connected 48 3-in., perforated, cast-iron laterals. In order to furnish equal distribution of drainage and wash, each lateral has 27 quarter-inch perforations.

The rate of filtration can be controlled in two ways. In the first place, each filter has a rate controller of the Venturi type, suitable for operation at a maximum rate of 0.75 m.g.d., by means of which a constant rate of filtration can be maintained. In the second place, there is a float control arranged to maintain a constant water level of 4 ft. over the filter sand. With the float control, it is possible to operate the plant with less uncertainty during periods when it is not attended.

Each filter is equipped with a control table, together with indicating charts for loss of head and rate of filtration. Wash water is supplied from the Great Hill standpipe through a 16-in. pipe. Rate and quantity are measured by a Venturi meter, 16 in. by 8 in., and the rate of wash is controlled by a Builders Iron Foundry rate controller. The normal washing rate is about 4.5 m.g.d., which amounts to a rise of nearly 30 in. per minute. Filter washings are discharged into the 18-in. drain line and conveyed to the swampy area at the northerly end of Cape Pond.

Clear-Water Reservoir. The clear-water reservoir is a circular, reinforced-concrete tank with a concrete dome roof, covered with earth. The reservoir has an inside diameter of 32 ft., an effective depth of 10

ft., and a capacity of 60,000 gal. There is a small sump for filtered-water discharge and high-lift-pump suction lines. Construction of the reservoir is shown in Figure 2.

FIG. 2.—ROCKPORT, MASS. CLEAR-WATER RESERVOIR UNDER CONSTRUCTION.

High-Lift Pumps. The high-lift pumps consist of two Allis-Chalmers, single-stage, centrifugal pumps powered by 40-h.p., splash-proof, induction motors. Each pump is rated at 700 g.p.m. against a head of 150 ft. and is arranged to operate singly.

Automatic priming is maintained by a small Nash vacuum pump, connected to a vacuum tank, which in turn is connected to the pump casings. Crispin air valves in the system provide for air relief at the pumps. The pump discharge is measured by a Venturi meter, 12 in. by 6 in.

Control Panel. In the filter gallery is located a central control panel, on which are mounted all major recording instruments. These include level recorders for the Great Hill and Pigeon Hill standpipes and the filtered-water reservoir. A flow meter shows the rate and quantity of filtered water pumped and another gives the rate and quantity of wash water used. There is an electric switch for remote control of an electric valve in the Great Hill influent line.

TABLE 5—SUMMARY OF OPERATION OF GREAT HILL FILTER PLANT, ROCKPORT, MASS.
(From reports of Lewis C. Sanborn, Superintendent of Water Works)

Month	Quantity of raw water (m.g.d.)	Rate of filtration (m.g.d. per acre)	Average length of filter runs (hr.)	Per cent wash water	Quantity of chemicals applied Pounds per mil. gal.			
					Alum	Lime	Carbon	Chlorine
1939								
Sept.	0.443	101.5	21.7	6.8	458	214	11.1	4.1
Oct.	0.284	104.2	21.8	7.1	746	419	27.8	3.9
Nov.	0.223	109.7	18.3	7.2	1174	601	43.1	4.5
Dec.	0.223	107.4	15.5	8.1	1350	668	55.1	4.9
1940								
Jan.	——	——	——	—	——	—	——	—
Feb.[1]	0.233	104.1	24.7	6.4	1081	653	21.9	5.6
Mar.	0.241	102.3	20.3	5.4	747	614	17.0	4.6
Apr.	0.257	107.6	19.9	5.1	370	382	0.0	5.1
May	0.129	107.7	17.9	4.7	659	504	0.0	3.9
Jun.	0.287	112.1	15.1	7.0	394	278	0.0	4.2
Jul.	0.471	107.4	12.7	10.6	310	246	0.0	4.5
Aug.	0.636	104.0	16.5	9.4	258	174	13.4	5.0
Sept.	0.369	108.1	21.0	5.7	434	279	22.2	4.9
Oct.	0.262	106.3	18.3	6.1	607	378	7.3	5.3
Nov.	0.160	101.3	17.3	5.6	850	569	5.0	5.6
Dec.[2]	0.046	94.8	26.5	2.2	2220	1471	0.0	6.5
Ave. for 14 months[3]	0.302	106.0	18.6	6.8	583	367	14.9	4.6
1941								
Jan.[4]	0.041	67.4	——	0.0	1609	1096	0.0	9.8
Feb.[5]	0.053	81.8	——	20.8	755	426	34.0	5.7
Mar.[6]	0.132	113.0	——	27.3	1038	723	68.1	7.6
Apr.[7]	0.121	116.1	12.3	8.3	877	660	79.3	7.4
May	0.122	84.5	16.6	6.6	786	563	59.0	5.7
June	0.434	108.3	16.3	6.2	318	244	22.1	5.3
July	0.620	103.1	14.2	7.4	247	186	15.2	6.5
Aug.	0.536	99.9	20.6	5.0	289	200	18.5	6.9
Sept.	0.493	98.7	11.6	11.2	359	196	20.1	5.7
Oct.	0.289	95.9	19.0	5.9	564	320	31.8	5.2
Nov.	0.176	89.1	26.0	5.1	716	446	47.1	6.8
Dec.	0.173	97.1	16.7	6.4	717	484	46.2	6.9
Ave. for May to Dec., incl.	0.355	97.1	17.6	6.7	500	330	32.5	6.1

[1]Plant operated only 20 days in month.
[2]Plant operated only 10 days in month.
[3]Excluding December, 1940.
[4]Plant operated only 4 days in month.
[5]Plant operated only 3 days in month.
[6]Plant operated only 1 day in month.
[7]Plant operated only 12 days in month.

General. The general construction of all parts of the filter building below ground level is of reinforced concrete. Native, Rockport, seam-face granite was used for the outside walls of the superstructure and buff tile was employed on inside walls and partitions. The type of architecture selected is that typical of old Cape Ann, and the filter plant harmonizes with its rocky environment. See Figure 1.

Operation. Ordinarily the filter plant is to be operated during the summer and fall months only, since the Mill Brook Valley development is expected to supply sufficient water during the winter and spring months in years of normal rainfall.

The filter plant was completed early in July, 1939, and immediately placed in operation. In general, sulfate of alumina has been used in quantities ranging from about 200 to 1,300 lb. per m.g. and activated carbon in quantities at times as great as 60 lb. per m.g. The lime treatment has required about 150 to 600 lb. per m.g. The color of the raw water has been reduced from as high as 100 at times to an average of less than 10, and objectionable tastes and odors have been entirely removed. Data on the operation of the filter plant are given in Table 5, and the results of analyses of raw water and filtered water are presented in Table 6.

The cost of water purification and pumping for the year 1941, including copper sulfate treatment of the pond, operation of the filter plant, both high- and low-lift pumping, and technical supervision, follows:

Labor	$4,653.66
Fuel, light and power	4,977.09
Chemicals	728.56
Repairs and maintenance	565.06
Miscellaneous	692.05
Total	$11,616.42
Per million gallons delivered	$140.90

It is impossible to give the cost of filtration alone because labor, fuel, light and power costs cover both pumping and filtration.

Cost of Filtration Plant. The construction cost of the Great Hill filter plant, including engineering, supervision and administrative costs, was as follows:

TABLE 6—AVERAGE CHEMICAL ANALYSES AND RANGE OF BACTERIOLOGICAL ANALYSES OF RAW AND FILTERED WATER FROM CAPE POND SUPPLY, ROCKPORT, MASS.
(As reported by Metcalf & Eddy)

Period covered by analyses	Samples	Color (p.p.m.)	Free carbon dioxide as CO_2 (p.p.m.)	Total alkalinity $CaCO_3$ (p.p.m.)	Hardness as $CaCO_3$ (p.p.m.)	Hydrogen-ion concentration (pH index)	Iron as Fe (p.p.m.)	Total Count 24-hr. 37°C.	Total Count 48-hr. 20°C.	Coliform Organisms in 10 ml. Ratio of positive to negative tests
Sept., Oct., & Nov., 1939	Raw water	81	5.3	8.1	22.3	6.3	1.20	9—415	9—750	1/4—5/0
	Filtered water	14	16.0	4.5	36.8	4.9	0.00	1—1,520	1—675+	0/5—1/4
	Per cent reduction	82.7	Increase	—	——	—	100.0	——	——	——
Apr. to Dec., 1940	Raw water	39	6.6	6.5	24.6	6.0	0.91	2—15	5—6,000	0/5—4/1
	Filtered water	6	3.2	13.2	36.4	7.4	0.04	0—1,800	0—10,000	0/5—0/5
	Per cent reduction	84.6	51.5	—	——	—	95.6	——	——	——
Jan. to Dec., 1941	Raw water	56	3.2	5.3	26.8	6.0	1.28	1—8,000±	2—10,000±	0/5—5/0
	Filtered water	7	0.7	12.9	49.9	7.7	0.08	0—350	1—335	0/5—2/3
	Per cent reduction	87.5	78.2	—	——	—	93.7	——	——	——

Total cost	$88,961.91
Received from P.W.A.	38,250.00
Net cost to town	$50,711.91

The site of the filter plant was on a rocky hill-top. Many large boulders were encountered in excavation for pipe trenches and much of the excavation for the plant was in ledge. The large amount of rock excavation, coupled with the small size of the plant, resulted in a relatively high cost per million gallons of plant capacity.

Personnel. The construction work on the Mill Brook Valley development was carried out by the following contractors:

Driving wells—Edward F. Hughes, Boston

Installation of connecting piping—C. Reppucci & Sons, Inc., Boston

Pumping-station building—Hobbs and Mackey, Rockport

Pumping-station equipment—Ralph P. Hall, Inc., Boston

The general contractor for the Great Hill filter plant was Walter L. Ritchie of Somerville, and all mechanical equipment was installed by Norwood Engineering Co. of Northampton, Mass.

During all phases of design and construction, the town of Rockport was represented by a Special Water Committee, of which Addison B. LeBoutillier was Chairman. The water-works improvements were designed and construction was supervised by Metcalf & Eddy, for whom Frank A. Nicoli was Resident Engineer. P.W.A. was represented by William B. Wiggin as Resident Engineer Inspector. Operation of the works is under the general direction of a board of Water Commissioners of which Ivan K. Grover is chairman. L. C. Sanborn, Superintendent of Water Works, is in direct charge.

SALT CONTENT OF WELLS IN MASSACHUSETTS AFFECTED BY THE TIDAL WAVE AND HURRICANE OF 1938

BY VINCENT M. HYNES*

[*Received September 16, 1942.*]

The tidal wave that accompanied the New England hurricane of September 21, 1938, caused untold destruction in the southeasterly section of Massachusetts. Many hundreds of homes were completely destroyed, public utilities were severely damaged, and the shore line was changed in several places. In one sea-side colony, 300 summer cottages were washed away during the storm and never found as structures again. Aside from the loss of life and property damage, one of the noticeable after effects of the tidal wave was the salting of the water of several hundred private wells that were located on land washed by salt water.

The Massachusetts Department of Public Health through its Division of Sanitary Engineering investigated several water supplies in the devastated area. Numerous private wells were examined in the Sconticut Neck section of Fairhaven; the beach locations and the Oakdale and Indian Neck sections of Wareham; the various coastal villages of the town of Bourne; and a portion of Dighton which was flooded with tidal water from the Taunton River. To a lesser extent, wells were examined in the coastal areas of the towns of Westport, Dartmouth, Mattapoisett, Marion and Falmouth, all of which border Buzzards Bay; in Berkley and Somerset near the Taunton River; and in Swansea near the tidal waters of Mount Hope Bay.

The outstanding complaint made by people using these private wells concerned the distinct salt taste of the water. In dug wells, into which salt water entered directly, the salt taste was observed almost immediately; in tubular wells, however, no taste was observed until about 10 to 12 days after the hurricane. This lapse of time is explained by the fact that the points of the tubular wells were situated some distance below the ground surface and the salt water had not

*Massachusetts Department of Public Health, Boston, Mass.

yet penetrated the ground to the depth from which water was being pumped.

To help in cleaning out wells, the fire departments in many towns pumped them dry three or four times after treating the water with chlorinated lime. An improvement in the bacterial quality of the water was observed in some instances, but such pumping caused a decided increase in the salt content of the water. As a result, excessive pumping was generally stopped as soon as the wells were safe to be used for drinking purposes as determined by bacteriological examinations.

Since the hurricane, about 575 examinations have been made of wells in the salted areas, and certain wells have been re-examined at intervals to determine the variation in their salt or chloride content, particularly in the towns of Dighton, Wareham and Fairhaven. Before discussing this subject further, it might be well to point out that sea water has a chloride content of from 16,000 to 18,000 p.p.m. and that the U. S. Treasury Standard for chlorides is 250 p.p.m. The normal chloride content for natural unpolluted waters for this portion of Massachusetts varies from 4.0 p.p.m. in Dighton to about 10 p.p.m. or less in the town of Bourne. The experience of the Department of Public Health shows that a definite salt taste is evident when the chloride content is 500 p.p.m., with some people able to detect a salt taste at lower amounts, depending on the sensitivity of their taste mechanism. The effect of such sources of pollution as cesspools on the chloride content of the wells has not been considered, due to the fact that the amount of chlorides added to the ground water from the tidal wave is of such magnitude as to pale other sources of chlorides into insignificance as far as the purpose of this paper is concerned.

In a group of 44 wells examined in Dighton in October, 1938, the maximum chloride content was 2680 p.p.m. and the average 735 p.p.m. A set of 23 samples collected on November 4, 1941, showed a maximum chloride content of 770 p.p.m. and an average of 135 p.p.m. This is a reduction in the average salt content of 82 per cent made possible by the cleansing action of 132 in. of rain falling on the ground in this vicinity since the time of the hurricane. Twenty of the 23 samples were lower than the U. S. Treasury Standard of 250

p.p.m., with two determinations still in excess of 500 p.p.m., sufficient to cause a salt taste in these two instances. See Figure 1.

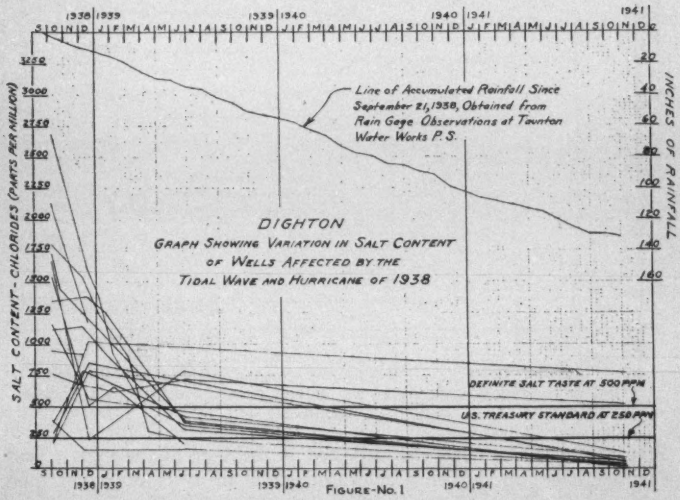

1938 1939 1939 1940 1940 1941 1941
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
SALT CONTENT - CHLORIDES (PARTS PER MILLION)
INCHES OF RAINFALL
20
40
60
80
100
120
140
160
Line of Accumulated Rainfall Since September 21, 1938, Obtained from Rain Gage Observations at Taunton Water Works P.S.
DIGHTON
GRAPH SHOWING VARIATION IN SALT CONTENT OF WELLS AFFECTED BY THE TIDAL WAVE AND HURRICANE OF 1938
DEFINITE SALT TASTE AT 500 PPM
U.S. TREASURY STANDARD AT 250 PPM

FIGURE-No. 1

In a group of 25 wells examined in Wareham in November, 1938, the maximum chloride content was 3820 p.p.m. with an average of 630 p.p.m. A group of 13 samples collected in November, 1941, showed a maximum chloride content of 710 p.p.m. and an average of 110 p.p.m. This is a reduction in the average salt content of 83 per cent during a time when 153 in. of rain fell on the ground in this vicinity. Twelve of the 13 samples were within the U. S. Treasury Standard of 250 p.p.m. See Figure 2.

At Fairhaven, a group of 62 wells examined in October, 1938, showed a maximum chloride content of 5160 p.p.m. with an average of 830 p.p.m. Thirteen samples collected in November, 1941, showed a maximum chloride content of 530 p.p.m. and an average of 215 p.p.m. This is a reduction in average salt content of 74 per cent during a period when 123 inches of rainfall occured in this vicinity.

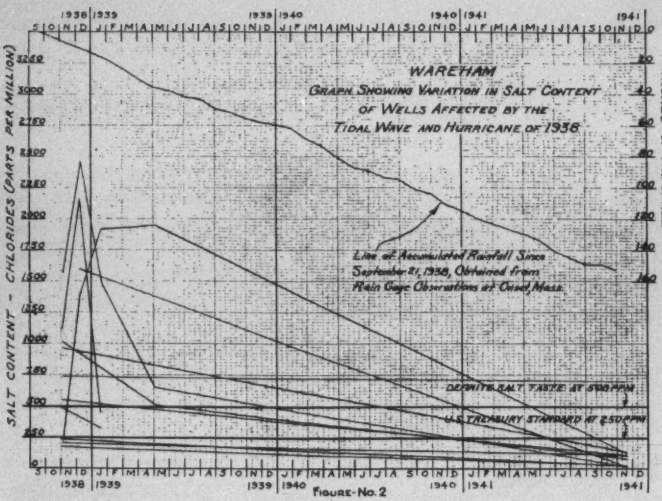

WAREHAM
GRAPH SHOWING VARIATION IN SALT CONTENT OF WELLS AFFECTED BY THE TIDAL WAVE AND HURRICANE OF 1938
SALT CONTENT - CHLORIDES (PARTS PER MILLION)
INCHES OF RAINFALL
Line of Accumulated Rainfall Since September 21, 1938, Obtained from Rain Gage Observations at Cuttyhunk
DEFINITE SALT TASTE AT 5,000 P.P.M.
U.S. TREASURY STANDARD AT 2,500 P.P.M.
1938 1939 1939 1940 1940 1941 1941

FIGURE-No. 2

Five of the thirteen samples collected at the time of the most recent examinations still showed a chloride content of over 250 p.p.m., and only one sample showed more than 500 p.p.m. See Figure 3.

As a result of these detailed investigations, it was observed that wells located near the outer limits of ground affected by salt water during the hurricane reduced their chloride content much lower than wells located nearer tidal water. This indicates that the cleansing action of rainfall assisted by ground water flow is washing salt from the outer fringe of land at the high-water mark of the tidal wave back towards the normal tide water limits. The chloride content of wells in Fairhaven is seen to be higher at the present time than in the Dighton and Wareham wells, due principally to the fact that a larger area of salted ground is draining towards many of the Fairhaven wells. The smaller amount of rainfall in the Fairhaven area must also be considered a factor.

Some property owners in the flooded areas attempted to hasten the leaching action of rainfall by piling the snow of the winter months

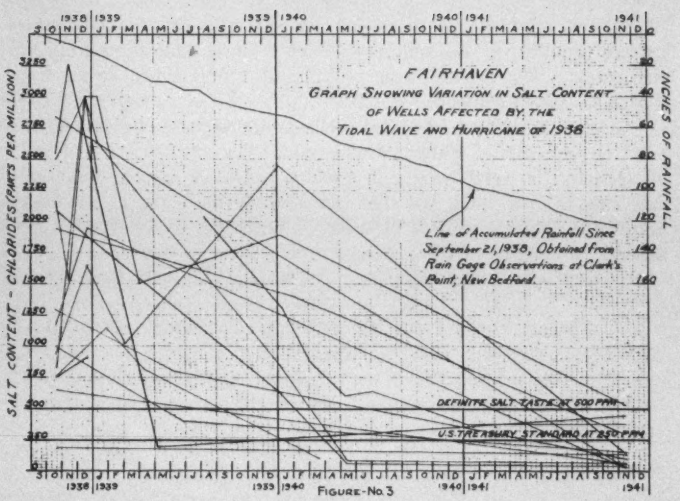

FAIRHAVEN
GRAPH SHOWING VARIATION IN SALT CONTENT OF WELLS AFFECTED BY THE TIDAL WAVE AND HURRICANE OF 1938
Line of Accumulated Rainfall Since September 21, 1938, Obtained from Rain Gage Observations at Clark's Point, New Bedford.
DEFINITE SALT TASTE AT 500 P.P.M.
U.S. TREASURY STANDARD AT 250 P.P.M.
SALT CONTENT - CHLORIDES (PARTS PER MILLION)
INCHES OF RAINFALL
1938 1939 1939 1940 1940 1941 1941

FIGURE-No. 3

around their wells and, in the case of dug wells, also by dumping snow directly into the wells. As long as the snow was concentrated onto strips of land aligned with the direction of ground water flow where ground water was tapped by wells, beneficial results in reducing the salt content of the water were observed.

Examinations of wells that were drilled through rock and properly sealed at the entrance into rock showed that the tidal wave had little if any effect on the chloride content of these wells. In an area on Sconticut Neck, where shallow dug and tubular wells showed excessive salt content, a well was drilled 60 ft. into rock about two months after the hurricane. A sample of water from this well contained only a small amount of chlorides, giving no indication of salt water contamination. A group of drilled wells in the flooded Antassawamock section of Mattapoisett also yielded the same results.

The tidal wave, a happening of nature unusual to New England, afforded a splendid opportunity to observe on a large scale the ability of rains to wash substances such as salt from the ground. This action

of rainfall might serve to explain in part the chloride content of certain supplies in Massachusetts which is lower than the normal for the region. The ground water supply of Camp Edwards on Cape Cod is a case in evidence.

The investigation of salted wells undertaken by the Massachusetts Department of Public Health shows that the majority of wells affected by the tidal wave now yield a palatable water so far as a salt taste is concerned, but that considerably more time must elapse before the chloride content of these wells returns to a condition normal for this region of the country.

DETERMINATION BY STATISTICAL METHODS OF THE AVERAGE SERVICE LIFE OF 6-INCH CAST-IRON WATER MAINS IN BROOKLYN, NEW YORK

BY A. V. RUGGLES*

[*Read September 25, 1941.*]

In 1934, the Water Bureau of the Public Service Commission of the State of New York acquired detailed information from the Department of Water Supply, Gas and Electricity of the City of New York on the installation and removal of cast-iron water mains in Brooklyn. The information first received gave the statistics through 1932 and this was later supplemented by similar figures to the end of 1936. The statistics covered pipe of sizes from 1½ to 12 in. Studies made by members of the Water Bureau staff have been confined almost entirely to 6-in. pipe.

Data. Of the two blueprints numbered 6870-G-6, received from the Water Department in 1934, the first gives for the Borough of Brooklyn, for pipe sizes of 1½ to 12 in. inclusive, and for each year from the beginning of the record (1859 and prior) to and including 1932, the number of linear feet of pipe installed. It also gives for each entry of pipe installed the part in linear feet since then removed or abandoned. The second print gives the same figures year by year for pipe installed and also gives for each size of pipe, for the period prior to 1897 and for individual years beginning with 1903, the total number of linear feet of pipe removed during that year regardless of when installed. On both prints, figures are given separately for pipe acquired by the City of New York from communities outside of the city and from private and public companies and organizations.

With the two blueprints, a set of fifteen typewritten tables gives in more detail the same figures that are summarized on the two blueprints. In these tables, for each size of pipe 4 to 12 in. in dameter inclusive and for each year of the record, figures are given showing the total length of pipe installed during that year and also the succes-

*Assistant Hydraulic Engineer, New York Public Service Commission.

sive parts of it in linear feet removed subsequently year by year and totaling to the figure on the blueprint.

In 1937, the data were supplemented by a set of four typewritten sheets extending through the years 1933 to 1936 inclusive and giving the same kinds of figures as for the previous years.

Studies to Determine the Average Service Life of 6-in. and 8-in. Pipe in Brooklyn. Studies to determine the average service life of 6-in. and 8-in. pipe in Brooklyn were made by several members of the Water Bureau staff, beginning in 1934, but the results do not appear to be of value. Since these earlier studies were made, a method of computation of life expectancy of physical property has been devised by C. B. Benson of the Public Service Commission's staff and used by him on the work of the Commission. This method is described in a monograph[1] by Benson written in 1937 entitled, "A Method for the Construction of Life Tables for Physical Property."

In 1938, D. D. Morey of the Water Bureau staff applied the Benson method to 6-in. pipe in Brooklyn, and Morey found it to be clearly indicated that the years 1904 to 1936 inclusive constitute the best band of years to work on.

Using the Benson method, Morey constructed a table of the form of Table 2 herewith, presenting the "Historical Arrangement of Mortality Data" and from the totals of the vertical columns thereon he calculated the total installations and retirements for each year of age. For each year of age, the ratio of feet of pipe retired to feet of pipe installed is the "Observed Retirement Ratio", and Table 3 is the table of observed retirement ratios made by Morey for ages zero to 75.5 years and for the band of years 1904 to 1936 inclusive. From the observed retirement ratios he then made an observed life table, and this he smoothed for every tenth year, using the Gompertz-Makeham method and also some types of mortality curves from "Valuation Engineering" by Marston & Agg. He obtained an average service life for the 6-in. pipe of 90.1 years.

Studies by the Writer of Average Service Life of 6-in. Pipe. Starting with the blueprints and typewritten sheets received from the Water Department, several analysis tables were made to bring the

[1]Reprinted as Pages 78-83 of the 1938 Report of the Committee on Depreciation of the National Association of Railway and Utility Commissioners.

TABLE 1.—TOTAL LINEAR FEET OF CAST-IRON PIPE, IN CITY SYSTEM, OF FOUR SIZES, INSTALLED AND REMOVED, AS OF DECEMBER 31, 1936

	4-in.	6-in.	8-in.	12-in.	Total
Installed by City—"City System"					
1904 to 1936, inclusive	——	321,397	——	——	——
1860 to 1903, inclusive	——	1,450,428	——	——	——
1860 to 1936, inclusive	11,461	1,726,825	3,114,078	801,184	5,653,548
1859 and prior	242	358,035	158,406	63,369	580,052
Sub-total—CITY SYSTEM	11,703	2,084,860	3,272,484	864,553	6,233,600
Acquired by City	185,956	513,061	110,806	43,913	853,736
Total installed	197,659	2,597,921	3,383,290	908,466	7,087,336
Total removed	83,316	639,061	147,491	46,520	916,388
Percentage removed	42.2	24.6	4.4	5.1	12.9
For the 6-in. pipe, studied in this paper:					
CITY SYSTEM					
Installed	——	2,084,860	——	——	——
Removed	——	504,464	——	——	——
Percentage removed	——	24.2	——	——	——
Acquired by City					
Installed	——	513,061	——	——	——
Removed	——	134,597	——	——	——
Percentage removed	——	26.2	——	——	——

data into the desired form, and Table 1 herewith gives, for 4-, 6-, 8-, and 12-in. pipe in the City System, i.e. installed by the City, the total linear feet installed from the beginning of the record (1859 and prior) to and including December 31, 1936. Over seven million linear feet of pipe have been installed of the four sizes given, with more 8-in. pipe than any other size. The table separates the pipe acquired by the City from pipe installed by the City—the latter being referred to repeatedly herein as City System. It became evident from a study of the record that satisfactory determinations of the length of average service life can be obtained only from pipe in the City System and by excluding all pipe installed earlier than 1860.

The record shows, for the years 1860 to 1936 inclusive, and for

"City System", that the combined number of feet of pipe of the four sizes mentioned laid each year varied from 8,954 to 222,090 and averaged 73,423.

The record of the 6-in. pipe is long, complete, and very satisfactory in that the percentage of removals to date has been quite substantial. This is not the case with the 8-in. pipe. Although the footage of 8-in. pipe is greater and although the record is equally long and complete, the percentage of removals is too small to give an equally valuable determination of average service life.

The 6-in. and 8-in. pipe have not been used in the same way in the Borough of Brooklyn. Formerly, the 6-in. pipe constituted the greater percentage of the pipe in the system. Later, the custom was adopted of installing 8-in. pipe as the minimum size, except in a minority of cases. Six-inch pipe when removed was replaced by 8-in. pipe or larger, and the necessity for removal of 8-in. pipe has not as yet become as frequent as for 6-in. pipe.

The Department of Water Supply, Gas and Electricity states that the preponderant use of 8-in. mains for extensions commenced in Brooklyn as far back as 1903, when an extensive program of strengthening the distribution system in that borough was initiated, following the need indicated by the Academy of Music fire during that year. At about the same time, the National Board of Fire Underwriters recommended the use of 8-in pipe as minimum size for adequate fire protection in urban areas. The statement of the D.W.S.G.E. that the amount of 6-in. pipe installed annually in Brooklyn began to decrease at about that time is borne out by the record:

	Average Linear Feet of 6-in. Pipe Installed Annually
1860 to 1903	31,942
1904 to 1936	9,739
1906 to 1936	7,469

The studies herein described were based on the band of years from 1904 to 1936, so it may be considered that the policy of using 8-in. pipe for minimum size for installations and replacements prevailed during the period of years upon which these studies were based.

In the record, removals prior to 1897 are given separately, those

6-30-28

| Year | Total Plant in Service Jan. 1 | Total Net Increments during Year | Total Gross Increments from this Plant during Year | AGE OF PLANT REMAINING JAN. 1 OF ANY YEAR | | |

38.5	39.5	40.5	41.5	42.5	43.5	44.5	45.5	46.5	47.5	48.5	49.5	50.5	51.5	52.5	53.5	54.5	55.5	56.5	57.5	58.5	59.5	60.5	61.5	62.5	63.5	64.5	65.5	66.5	67.5	68.5	69.5	70.5	71.5	72.5	73.5	74.5	75.5	76.5	Check Column
1865	1864	1861	1862	1861	1860																																		
22,951	28,758	27,598	48,734	19,975	42,170																																		1,699,772
2,504	320	108	1,458	580	192																																		
19,541	20,453	24,438	27,490	45,276	19,195	41,976																																	1,471,442
				50	70	30																																	
46,270	19,541	20,453	24,438	27,490	45,226	19,196	41,948																																1,497,887
1,446	61		300		64	520	380																																
46,605	44,984	19,480	20,455	24,138	27,490	45,262	18,865	41,568																															1,493,321
2,155	144	220	649	101	111	1,378	236	1,620																															
87,333	44,450	47,780	19,260	19,804	24,037	27,357	43,784	18,629	39,944																														1,489,336
4,661	8,839	1,386	201	180	1,322	771	780	68																															
67,935	82,672	41,634	43,394	19,059	19,628	22,715	26,586	43,004	18,58	39,944																													1,468,046
1,480	1,888		517	589		528			1,100	16																													
74,218	66,455	80,784	41,034	42,805	19,059	19,628	22,191	26,586	43,004	17,161	39,785																												1,468,610
4,618	2,302	2,268		133	550																																		
41,087	69,580	64,151	78,516	41,034	42,662	18,509	19,628	22,191	26,586	41,004	17,161	39,785																											1,460,863
1,810	2,440	70			70																																		
70,321	39,277	67,140	64,083	78,516	41,034	42,592	18,509	19,628	22,191	26,586	43,004	17,161	39,785																										1,466,814
364																																							
50,918	70,556	39,277	67,140	64,083	78,516	41,034	42,592	18,509	19,628	22,191	26,586	43,004	17,161	39,785																											1,470,170
830	25	991	39																																				
19,697	50,088	70,531	38,284	67,101	64,083	78,516	41,034	42,592	18,509	19,628	22,191	26,586	43,004	17,161	39,785																										1,470,916
	1,783	1,314	221	224	794	1,101	1,052	1,185				75	1,446	75																									
13,431	19,697	48,305	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,628	22,191	26,511	41,558	17,086	39,785																							1,460,344
28,789	13,431	19,697	48,305	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,628	22,191	26,511	41,558	17,086	39,785																						1,465,974
15,911	28,789	13,431	19,697	48,305	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,628	22,191	26,511	41,558	17,086	39,785																						1,472,330
13,667	15,911	28,789	13,431	19,697	48,305	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,628	22,191	26,511	41,558	17,086	39,785																						1,474,804
13,741	13,667	15,911	28,789	13,431	19,697	48,305	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,628	22,191	26,511	41,558	17,086	39,785																						1,477,289
10,649	13,741	13,667	15,911	28,789	13,431	19,697	48,305	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,628	22,191	26,511	41,558	17,086	39,785																						1,440,685
11,134	10,649	13,741	13,667	15,911	28,789	13,431	19,697	48,305	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																						1,488,289
11,835	11,134	10,649	13,741	13,667	15,911	28,789	13,431	19,697	48,305	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																						1,495,277
						670			2,718																																
29,579	11,835	11,134	10,649	13,741	13,667	15,911	28,118	13,431	19,697	45,850	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																	1,500,748
15,709	29,579	11,835	11,134	10,649	13,741	13,667	15,911	28,115	13,431	19,697	45,592	69,213	38,061	66,877	61,32	77,415	39,942	41,407	16,509	19,624	22,191	26,511	41,558	17,086	39,785																	1,518,133
				575									770																												
29,957	15,709	29,579	11,835	11,134	10,074	13,741	13,667	15,911	28,119	13,431	19,697	45,592	69,213	38,093	66,877	61,329	77,415	39,942	41,407	16,509	19,624	22,191	26,511	41,558	17,086	39,785																	1,519,884
							1,385												900		785																				
16,188	29,957	15,709	29,579	11,835	11,134	10,074	13,741	12,462	15,911	28,119	13,431	19,697	45,592	69,213	38,093	66,877	61,329	77,415	39,942	40,507	16,509	16,839	22,191	26,511	41,558	17,086	39,785																	1,523,976
35,533	16,188	29,957	15,709	29,579	11,835	11,134	10,074	13,741	12,462	15,911	28,119	13,431	19,697	45,592	69,213	38,093	17,293	66,877	61,329	77,415	39,942	40,507	16,509	16,839	22,191	26,511	41,558	17,086	39,785																	1,528,998
																1,586	268																								
19,794	35,533	16,188	29,957	15,709	29,579	11,835	11,134	10,074	13,741	12,462	14,941	28,119	13,431	19,697	45,590	67,627	17,025	66,877	61,329	77,415	39,942	40,507	16,509	16,839	22,191	26,511	41,558	17,086	39,785																	1,533,907
			1,598						570		285	405	740				2,183																								
44,597	19,794	35,531	16,188	28,368	15,709	29,579	11,835	11,134	10,074	13,741	12,462	14,656	23,784	12,691	19,597	45,590	67,627	17,025	64,694	63,329	77,415	39,942	40,507	16,509	16,839	22,191	26,511	41,558	17,086	39,785																	1,527,467
		70	33	626					120		406				248	1,671	645	886	3,683	1,711	1,349	600	175	400	439	65	650	275	25	740																	
37,423	44,597	19,795	35,461	35,857	27,715	15,709	29,579	11,835	11,134	9,754	13,741	12,076	14,656	23,784	12,691	19,449	43,919	66,982	16,138	61,011	61,598	76,066	39,142	40,332	16,109	18,400	22,126	25,861	41,283	17,061	39,045																	1,518,948
1,468	1,920		224	1,035			1,451				713	1,095			134			520	1,202	1,536	1,046	1,393	2,478	775	81	1,557	817		2,142	757	2,070																	
35,806	35,962	42,677	19,792	35,857	34,828	27,757	15,709	28,188	11,835	11,134	9,754	13,028	10,981	14,656	23,734	12,546	19,449	43,919	66,162	34,917	59,475	60,553	74,671	16,864	39,557	18,028	16,843	21,309	25,861	39,141	16,304	16,975																	1,493,197
3,168	2,717	765	2,893		500	406	361	412	380	690		540	289	760	681	665		1,119	2,168	836	2,171	1,915	1,517	976	2,494	780	1,291		2,602	564	975	320																	
28,846	32,641	33,245	41,912	16,899	35,237	34,328	27,331	15,394	27,716	11,355	10,444	9,754	12,468	10,692	13,896	21,033	11,881	19,449	42,800	61,994	34,099	57,104	58,638	73,136	35,858	37,063	17,248	15,552	21,309	23,259	38,577	15,329	36,655						1,488,891
												61								1,140			775	127															
15,937	28,846	32,641	33,245	41,912	16,899	35,237	34,328	27,331	15,394	27,716	11,355	10,444	9,754	12,427	10,692	13,896	23,033	11,881	19,449	42,800	62,854	34,099	57,104	57,861	72,809	35,858	37,063	17,248	15,552	21,309	23,259	38,577	15,329	36,655						1,488,839
								613															1,570				850					1,750							
10,501	15,937	28,846	32,641	33,245	41,912	16,899	35,237	34,328	26,718	15,394	27,716	11,355	10,444	9,754	12,427	10,692	13,896	23,033	11,881	19,449	42,800	62,854	34,099	55,514	57,861	72,809	35,858	16,213	17,248	15,552	21,309	23,259	36,827	15,329	36,655				1,481,897
																1,730	1,385						430	530				2,761											
10,039	10,501	15,937	28,846	32,641	33,525	41,912	16,899	35,237	34,328	26,718	15,394	27,716	11,355	10,444	9,754	12,427	8,962	12,511	23,033	11,581	19,449	42,800	62,854	33,668	55,004	57,861	72,809	35,668	33,452	17,248	15,552	21,309	23,259	36,827	15,329	36,655			1,445,446
		740		1,780					718									1,060					618		1,290	1,320			600			780							
13,968	10,039	10,501	15,137	28,846	32,641	33,525	41,912	16,899	35,237	33,610	26,718	15,394	27,716	11,355	10,444	9,754	12,427	8,962	11,451	23,033	11,581	19,449	42,800	62,216	33,669	51,714	56,543	72,809	35,888	32,852	17,248	15,552	20,529	28,269	26,827	15,329	36,826		1,482,940
		150													710			830					742	4,100		660	440	1,425	500	1,070				420	490	2,726			
1,474	13,968	9,885	10,501	15,197	28,846	32,641	33,525	41,912	16,899	35,237	33,610	26,718	15,394	27,716	11,355	9,734	9,754	12,427	8,132	11,451	23,033	11,581	19,449	42,058	58,116	33,669	52,854	56,103	71,384	35,388	29,782	17,248	15,552	20,529	22,329	26,327	18,904	36,655	
1026530	1012883	1014027	1043725	1038005	1046100	1009844	972,938	925,542	904,795	863,975	828,544	800,430	782,957	751,935	738,609	726,541	712,451	697,996	662,966	661,262	634,984	617,853	594,496	544,113	478,869	440,826	383,460	323,309	267,464	206,207	171,294	151,001	132,599	118,470	88,811	61,984	36,655	0	66,914,958
28,317	16,362	8,535	10,698	8,329	3,619	5,380	5,485	1,446	5,533	1,823	1,404	2,115	3,306	835	3,370	4,134	2,030	6,898	8,253	5,245	5,550	1,908	8,325	7,108	4,304	4,582	4,048	4,461	5,869	5,131	3,049	2,850	-	420	490	2,726	-	0	

6-30-38

AGE OF PLANT REMAINING JAN. 1 OF ANY YEAR

YEAR	TOTAL PLANT IN SERVICE END. $	TOTAL NET SALVAGE IN PLANT DURING YEAR	PLANT ADDED DURING YEAR FROM THIS PLANT DURING YEAR	0-.5	.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-8.5	8.5-9.5	9.5-10.5	10.5-11.5	11.5-12.5	12.5-13.5	13.5-14.5	14.5-15.5	15.5-16.5	16.5-17.5	17.5-18.5	18.5-19.5	19.5-20.5	20.5-21.5	21.5-22.5	22.5-23.5	23.5-24.5	24.5-25.5	25.5-26.5	26.5-27.5	27.5-28.5	28.5-29.5	29.5-30.5	30.5-31.5	31.5-32.5	32.5-33.5	33.5-34.5	34.5-35.5	35.5-36.5	36.5-37.5	37.5-38.5
				1903	1902	1901	1900	1899	1898	1897	1896	1895	1894	1893	1892	1891	1890	1889	1888	1887	1886	1885	1884	1883	1882	1881	1880	1879	1878	1877	1876	1875	1874	1873	1872	1871	1870	1869	1868	1867	1866	1865
1904	1,405,725		55,047	40,313	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,733	21,794	32,112	39,165	39,964	38,381	21,650	37,942	38,295	31,832	16,735	31,620	13,717	11,886	10,781	16,878	16,454	20,866	26,286	16,011	34,662	55,063	78,641	46,186	79,383	79,080	35,826	49,017	46,507	19,607	22,9
		22,130											40	200		385	58	30	38		35	58			60		153		20	800	48	70	1,829	2,971	3,089	788	1,848	867	1,819	237	66	2,5
1905	1,436,632		38,810	55,047	40,313	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,733	21,794	31,812	39,165	39,583	38,327	23,560	37,608	38,295	31,397	16,677	31,620	13,717	11,296	10,781	16,728	15,454	20,846	25,456	15,963	24,582	53,454	75,670	42,066	78,565	77,835	93,239	47,498	46,270	19,5
		1,581																											80				150	70		30	70	140	831		
1906	1,449,899		17,958	38,810	55,047	40,313	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,733	21,794	31,812	39,165	39,583	48,327	21,560	37,608	38,295	31,397	16,677	31,620	13,717	11,296	10,781	16,728	15,454	20,766	25,456	15,963	24,582	53,304	75,800	42,066	78,835	77,488	93,099	46,605	46,2
		7,708																					271		1,015	75						17	586			71	69	2,981			1,3
1907	1,460,249		13,172	17,958	38,810	55,047	40,313	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,733	21,794	31,812	39,165	39,583	48,327	21,560	37,608	38,296	31,397	16,406	31,620	13,717	11,296	10,781	16,728	15,454	20,766	25,456	15,963	24,582	53,304	75,800	41,998	78,466	74,484	93,099	46,6
		18,513														879									147				106	148	27	664	156		77	78	862		1,069	2,853	5,766	2,1
1908	1,473,807		38,329	13,172	17,958	38,810	55,047	40,313	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,733	20,875	31,812	39,165	39,583	48,327	47,959	21,560	37,606	38,295	31,319	16,406	31,473	12,702	11,221	10,781	16,728	15,454	20,766	25,456	15,963	24,582	53,304	75,800	41,995	77,392	78,031	87,1
		28,730														463	161		2,110	80	368		22		708	950	135	1,476	512				66	72	1,584	433	1,379	185	188	872	164	1,995	4,096	4,6
1909	1,492,526		9,520	38,329	13,172	17,958	38,810	55,047	40,313	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,870	20,812	31,812	17,055	39,503	47,359	21,836	37,608	37,589	30,369	16,273	29,997	12,390	11,221	10,676	16,812	15,365	18,548	24,567	14,567	23,764	83,038	39,866	41,995	75,832	67,9
		10,831															82			76			811			100		74			26	329	156	33	76	26		80	1,106		1,214	1,3
1910	1,457,215		6,199	9,520	38,329	13,172	17,958	38,810	55,047	40,313	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,870	20,330	31,812	36,979	39,505	47,969	20,727	37,608	37,589	30,269	16,273	29,923	12,390	11,221	10,649	16,183	16,199	18,618	24,789	14,541	23,764	82,968	72,761	41,995	78,2
		19,987	900																		70	1,036	200						152	147	564	304	47	87			1,823		151	574	1,787	1,700	908	4,6
1911	1,463,823		16,740	5,895	9,520	38,329	13,172	17,958	38,810	55,047	40,313	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,270	20,330	31,812	36,909	38,467	47,759	20,727	37,608	37,437	30,122	16,709	29,619	12,343	11,134	10,649	16,047	15,199	16,992	24,789	14,390	23,190	51,373	71,061	41,0
		9,973									23												70								70							70	140	140	1,8
1912	1,455,590		11,388	16,740	5,895	9,520	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,270	20,330	31,412	36,909	38,467	47,689	20,727	37,608	37,437	30,063	16,709	29,619	12,343	11,134	10,649	15,977	15,199	16,992	24,789	14,390	23,120	51,031	70,9
		8,015																				50	265			1,339	848	217	1,172	98		40	508				1,412			1,091	119	
1913	1,458,799		11,371	11,224	16,740	5,895	9,520	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,890	18,288	11,055	11,270	20,330	31,362	36,446	38,467	45,350	19,879	37,391	36,268	29,957	15,709	29,579	11,838	11,134	10,649	15,977	15,787	16,992	24,789	14,390	22,027	50,9
		8,966																																						2,130	
1914	1,465,384		5,732	11,371	11,224	16,740	5,895	9,520	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,890	18,288	11,055	10,501	20,330	31,362	36,446	38,467	45,350	19,879	37,391	36,268	29,957	15,709	29,579	11,838	11,134	10,649	15,977	15,787	16,992	24,789	14,390	19,6
		16,755						160																															1,081			
1915	1,459,161		6,183	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,559	18,288	11,026	10,501	20,285	31,362	36,576	38,197	45,706	19,792	35,531	36,188	29,957	15,709	29,579	11,838	11,134	10,649	13,741	13,667	15,911	24,789	13,5
		953																	65		40	26						300													
1916	1,459,893		5,183	6,183	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,474	18,248	11,000	10,501	20,285	31,362	36,576	38,187	45,406	19,792	35,531	36,188	29,957	15,709	29,579	11,838	11,134	10,649	13,741	13,667	15,911	24,7
1917	1,465,074		7,256	5,183	6,183	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	38,329	1,474	18,248	11,000	10,501	20,285	31,362	36,576	38,187	45,406	19,792	35,531	36,188	29,957	15,709	29,579	11,838	11,134	10,649	13,741	13,667	15,9
1918	1,478,330		2,476	7,256	5,183	6,183	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,474	18,248	11,000	10,501	20,285	31,362	36,576	38,187	45,406	19,792	35,531	36,188	29,957	15,709	29,579	11,838	11,134	10,649	13,741	13,6
1919	1,474,806		2,833	2,476	7,256	5,183	6,183	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,474	18,248	11,000	10,501	20,285	31,362	36,576	38,187	45,406	19,792	35,531	36,188	29,957	15,709	29,579	11,838	11,134	10,649	13,7
1920	1,477,839		3,450	2,833	2,476	7,256	5,183	6,183	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,474	18,248	11,000	10,501	20,285	31,362	36,576	38,187	45,406	19,792	35,531	36,188	29,957	15,709	29,579	11,835	11,134	10,6
		962						962																																	
1921	1,480,987		7,822	3,450	2,833	2,476	7,256	5,183	5,841	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,474	18,248	11,000	10,501	20,285	31,362	36,576	38,187	45,406	19,792	35,531	36,188	29,957	15,709	29,579	11,835	11,1
1922	1,488,980		9,308	7,822	3,450	2,833	2,476	7,256	5,183	5,841	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	38,810	55,047	40,290	32,280	18,371	8,257	14,312	1,474	18,248	11,000	10,501	20,285	31,362	36,576	38,187	45,406	19,792	35,531	36,188	29,957	15,709	29,579	11,8
		3,986						173																									390								
1923	1,493,653		7,117	9,308	7,822	3,450	2,833	2,476	7,085	5,181	5,841	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	38,810	38,047	40,290	32,280	18,370	8,257	14,312	1,474	18,248	11,000	10,501	20,285	31,362	36,576	37,797	45,406	19,792	35,531	36,188	29,957	15,709	29,4
1924	1,500,748		14,385	7,117	9,308	7,822	3,450	2,833	2,476	7,085	5,181	5,841	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	34,810	55,047	40,290	32,280	18,371	8,257	14,312	1,474	18,248	11,000	10,501	20,285	31,362	36,576	37,797	45,406	19,792	35,531	36,188	29,957	15,7
		4,008																				310						756					694				719				
1925	1,511,129		8,867	14,385	7,117	9,308	7,822	3,450	2,833	2,476	7,085	5,181	5,841	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	34,500	55,047	40,290	32,280	18,371	17,615	8,257	14,132	1,474	18,248	11,000	10,501	20,283	31,362	35,882	37,797	44,887	19,792	35,531	36,188	29,4
		8,870																																							
1926	1,516,716		6,560	8,867	14,385	7,117	9,308	7,922	3,450	2,833	2,476	7,085	5,181	5,841	5,732	11,371	11,224	16,740	5,895	9,360	38,329	13,172	17,958	34,500	55,047	40,290	32,280	17,615	8,257	14,132	1,474	18,248	11,000	10,501	20,283	31,362	35,882	37,797	44,887	19,792	35,531	36,1
		2,863																							840				275					1,348								
1927	1,520,813		7,995	6,560	8,867	14,385	7,117	9,308	7,922	3,450	2,833	2,476	7,085	5,181	5,841	5,732	11,371	11,224	16,740	5,895	9,360	14,429	13,172	17,958	34,500	54,207	40,290	32,280	17,615	7,982	14,132	1,474	16,900	11,000	10,501	20,283	31,362	35,882	37,797	44,687	19,792	35,5
		1,256						70														140															222				
1928	1,525,952		7,955	7,995	6,560	8,867	14,385	7,117	9,308	7,852	3,450	2,833	2,476	7,085	5,181	5,841	5,732	11,371	11,224	16,740	5,895	9,360	14,289	13,172	17,958	34,500	54,207	40,290	32,280	17,618	7,982	14,132	1,474	16,900	11,000	10,501	20,283	31,140	35,882	37,797	44,687	19,7
		11,282											25	77														67					1,524				2,061	1,016		61	90	
1929	1,522,885		8,232	7,955	7,995	6,560	8,867	14,385	7,117	9,308	7,852	3,450	2,833	2,851	7,008	5,181	5,841	5,732	11,371	11,224	16,740	5,895	9,360	14,289	13,172	17,958	34,500	54,207	40,233	32,280	17,618	6,812	14,132	1,474	16,376	11,000	10,501	18,232	30,122	35,882	37,794	44,4
		17,508																										860										726	278		313	
1930	1,509,969		5,993	5,232	7,955	7,995	6,560	8,867	14,385	7,117	9,308	7,852	3,450	2,833	2,851	7,008	5,181	5,841	5,732	11,371	11,224	16,740	5,895	9,360	14,289	13,172	17,958	34,500	53,347	40,233	32,280	17,618	6,812	14,132	1,474	16,376	11,000	10,501	17,5	35,882	35,882	37,7
		28,757																										520	2,855	50	43								380	153	74	1,4
1931	1,487,305		5,962	5,993	5,232	7,955	7,995	6,560	8,867	14,385	7,117	9,308	7,852	3,450	2,833	2,851	7,008	5,181	5,841	5,732	11,371	11,224	16,740	5,895	9,360	14,289	13,172	17,436	34,500	50,512	40,183	32,237	17,616	6,812	14,132	1,474	15,376	11,000	10,501	17,157	29,691	35,6
		31,826																												840				736	725		748	770		1,320	695	1,6
1932	1,491,761		5,550	5,962	5,993	5,232	7,955	7,995	6,560	8,857	14,385	7,117	9,308	7,852	3,450	2,833	2,851	7,008	5,181	5,841	5,732	11,061	11,224	16,740	5,895	9,360	14,289	13,172	17,436	34,500	49,672	40,183	32,237	17,615	6,020	13,407	1,474	14,628	10,230	10,501	15,937	28,7
		2,538																												216												
1933	1,490,773		2,856	1,550	5,962	5,993	5,232	7,955	7,995	6,560	8,857	14,385	7,117	9,308	7,852	3,450	2,833	2,851	7,008	5,181	5,841	5,732	11,061	11,224	16,740	5,895	9,360	14,289	13,172	17,436	34,286	49,672	40,183	32,237	17,615	6,020	13,407	1,474	14,628	10,230	10,501	15,7
		4,827																																						44		
1934	1,488,802		8,795	2,856	1,550	5,962	5,993	5,232	7,955	7,995	6,560	8,857	14,385	7,117	9,308	7,852	3,450	2,833	2,851	7,008	5,181	5,841	5,732	11,061	11,224	16,740	5,895	9,360	14,289	13,172	17,436	34,241	49,672	40,183	32,237	17,615	6,020	13,407	1,474	14,628	10,230	10,4
		9,769																																						640	196	
1935	1,481,833		1,611	8,795	2,856	1,550	5,962	5,993	5,232	7,955	7,995	6,560	8,857	14,385	7,117	9,308	7,852	3,450	2,833	2,851	7,008	5,181	5,841	5,732	10,988	11,224	16,740	5,895	9,360	14,289	13,172	17,436	34,241	49,672	40,183	32,237	17,615	6,020	13,407	1,474	13,988	10,0
		7,126																																							
1936	1,436,320		2,520	1,611	8,795	2,856	1,550	5,962	5,993	5,232	7,955	7,995	6,560	8,857	14,385	7,117	9,308	7,852	3,450	2,833	2,851	7,008	5,181	5,841	5,732	10,988	11,224	16,740	5,895	9,360	14,289	13,172	17,436	34,241	49,672	40,183	32,237	17,615	6,020	13,407	1,474	13,4
		17,389																																86	706	129						
1937	1,421,451			2,520	1,611	8,795	2,856	1,550	5,962	5,993	5,232	7,955	7,995	6,560	8,857	14,385	7,117	9,308	7,852	3,450	2,833	2,851	7,008	5,181	5,841	5,732	10,988	11,224	16,740	5,895	9,360	14,289	13,172	17,363	34,241	48,969	40,064	32,237	17,615	6,020	13,407	1,4
Total	Experience 1903-1936		581,797	758,890	389,557	405,133	410,534	421,296	418,551	430,776	436,599	440,154	454,151	479,040	509,571	515,154	518,691	486,516	516,134	546,504	476,894	489,925	712,895	720,110	724,487	726,717	726,178	729,674	730,124	744,990	749,894	758,197	797,117	864,672	858,665	880,711	917,121	969,887	996,404	1026511	1022154	1026
Total	Retirements	301,673	300	-	-	-	-	671	70	-	23	-	65	777	-	1,787	517	172	2,479	609	1,253	1,642	1,823	1,196	3,789	5,481	2,732	3,676	5,495	2,267	1,550	2,991	5,788	6,921	8,338	2,616	6,823	4,885	10,580	10,557	17,107	24,4

38.5	39.5	40.5	41.5	42.5	43.5	44.5	45.5	46.5	47.5	48.5	49.5	50.5	51.5	52.5	53.5	54.5	55.5	56.5	57.5	58.5	59.5	60.5	61.5	62.5	63.5	64.5	65.5	66.5	67.5	68.5	69.5	70.5	71.5	72.5	73.5	74.5	75.5	75.6	Check Column
1865	1864	1863	1862	1861	1860																																		
22,957	28,758	27,598	48,734	19,975	42,170																																		1,499,772
2,504	320	108	1,458	580	192																																		
19,541	20,453	28,438	27,490	45,276	19,395	41,978																																	1,471,442
				50	30	30																																	
46,270	19,541	20,453	28,438	27,490	45,226	19,365	41,948																																1,487,887
1,446	61		300		64	300	300																																
46,605	44,984	19,480	20,453	28,438	27,490	45,162	18,865	41,568																															1,493,321
2,155	134	220	649	101	111	1,178	216	1,620																															
87,133	44,450	43,780	49,260	19,804	28,037	27,357	43,784	18,629	39,944																														1,488,236
4,661	2,538	1,326	201	180	1,322	771	780	68																															
67,915	42,678	41,658	43,394	19,059	19,638	22,715	26,286	43,004	18,58	39,944																													1,468,046
1,480	1,588	97	589			524			1,100	165																													
74,218	66,455	80,784	41,034	42,805	19,059	19,624	22,191	26,586	43,034	17,161	39,785																												1,465,610
4,618	2,302	2,266		133	550																																		
41,087	69,580	64,151	78,516	41,034	42,662	18,509	19,624	22,191	26,586	43,034	17,161	39,785																											1,480,863
1,810	2,440	70			70																																		
70,921	19,277	67,141	64,083	78,516	41,034	42,592	18,509	19,624	22,191	26,586	43,034	17,161	39,785																										1,466,814
165																																							
50,918	70,556	39,277	67,140	64,083	78,516	41,034	42,592	18,509	19,624	22,191	26,586	43,008	17,161	39,785																										1,470,170
830	25	995	19																																				
19,697	50,088	70,531	38,284	67,101	64,083	78,516	41,034	42,592	18,509	19,624	22,191	26,586	43,008	17,161	39,785																										1,470,916
	1,781	1,318	221	224	794	1,101	1,058	1,185				75	1,446	75																										
13,431	19,697	48,305	69,213	38,061	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																							1,460,344
24,789	13,431	19,697	48,305	69,213	38,063	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																							1,465,074
15,911	24,789	13,431	19,697	48,305	69,213	38,063	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																							1,477,330
13,667	15,911	24,789	13,431	19,697	48,305	69,213	38,063	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																							1,474,806
13,741	13,667	15,911	24,789	13,431	19,697	48,305	69,213	38,063	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																							1,477,339
10,849	13,741	13,667	15,911	24,789	13,431	19,697	48,305	69,213	38,063	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																							1,460,689
11,134	10,849	13,741	13,667	15,911	24,789	13,431	19,697	48,305	69,213	38,063	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																							1,468,289
11,835	11,134	10,849	13,741	13,667	15,911	24,789	13,431	19,697	48,305	69,213	38,063	66,877	61,329	77,415	39,942	41,407	18,509	19,624	22,191	26,511	41,558	17,086	39,785																							1,497,877
						670			2,718																																			
29,579	11,835	11,134	10,849	13,741	13,667	15,911	24,119	13,431	19,687	45,820	69,213	38,063	66,877	61,329	77,415	39,942	41,407	16,509	19,624	22,191	26,511	41,558	17,086	39,785																	1,800,748
15,709	29,579	11,835	11,134	10,849	13,741	13,667	15,911	24,119	13,431	19,697	45,558	69,213	38,063	66,877	63,32	77,415	39,942	41,407	16,509	19,624	22,191	26,511	41,558	17,086	39,785																	1,518,133
				575									770																												
29,957	15,709	29,579	11,835	11,134	10,849	13,741	13,667	15,911	24,119	13,431	19,697	45,558	69,213	37,293	66,877	61,329	77,415	39,942	41,407	16,509	19,624	22,191	26,511	41,558	17,086	39,785																	1,519,586
							1,385												900		785																				
16,188	29,957	15,709	29,579	11,835	11,134	10,849	13,741	12,462	15,911	24,119	13,431	19,697	45,558	69,213	37,293	66,877	61,329	77,415	39,942	40,507	16,509	16,839	22,191	26,511	41,558	17,086	39,785																	1,582,276
35,531	16,188	29,957	15,709	29,579	11,835	11,134	10,849	13,741	12,462	15,911	24,119	13,431	19,697	45,558	69,213	37,293	66,877	61,329	77,415	39,942	40,507	16,509	16,839	22,191	26,511	41,558	17,086	39,785																	1,588,908
										970				268																													
19,794	35,531	16,188	29,957	15,709	29,579	11,835	11,134	10,849	13,741	12,462	14,941	24,119	13,431	19,697	45,558	67,627	37,025	66,877	63,329	77,415	39,942	40,507	16,509	16,839	22,191	26,511	41,558	17,086	39,785																	1,553,507
			1,594							285	405	740					2,183																									
44,597	19,794	35,531	36,188	28,36	15,709	29,579	11,835	11,134	10,849	13,741	12,462	14,656	23,78	12,692	19,697	45,558	67,627	37,025	64,694	63,329	77,415	39,942	40,507	16,509	16,839	22,191	26,511	41,558	17,086	39,785																	1,587,987
			33	626					320	406					240	1,671	645	686	3,683	1,731	1,349	600	175	400	439	65	660	275	25	740																	
37,483	44,597	19,794	35,861	35,838	27,13	15,709	29,579	11,835	11,134	9,754	13,741	12,076	14,656	23,78	12,691	19,449	43,919	66,982	16,139	61,011	61,598	76,066	39,942	40,332	16,109	16,400	22,126	25,861	41,283	17,061	39,045																	1,819,942
1,462	1,338		224	1,01					320	713	1,095				145			520	1,202	1,536	1,045	1,191	2,478	775	81	1,557	817		2,142	757	2,070																	
35,808	35,962	42,677	19,792	35,237	34,828	27,737	15,709	28,128	11,835	11,134	9,754	13,028	10,361	14,656	23,714	12,546	18,449	43,919	66,162	34,917	59,475	60,553	74,671	16,864	39,557	18,028	16,841	21,309	25,861	39,141	16,304	16,975																	1,493,187
3,19	2,717	765	8,893		500	406	361	412	380	690	940	289	760	681		665		1,119	2,168	638	2,171	1,915	1,537	976	2,944	780	1,291		2,602	564	975	320																	
28,846	32,643	33,245	41,912	16,899	35,237	34,328	27,331	15,348	27,716	11,455	10,444	9,754	12,488	10,692	13,896	23,033	11,881	19,449	42,800	63,994	34,099	57,104	58,638	71,136	35,888	17,063	17,248	15,552	21,309	23,259	38,577	15,329	36,655						1,488,891
										61										1,140			775	127															
19,97	28,846	32,643	33,245	41,912	16,899	35,237	34,328	27,331	15,348	27,716	11,455	10,444	9,754	12,427	10,692	13,896	23,033	11,881	19,449	42,800	62,854	34,099	57,104	57,861	72,809	35,888	17,063	17,248	15,552	21,309	21,259	38,577	15,329	36,655						1,488,639
									631														1,570				850					1,750							
10,501	19,97	28,846	32,643	33,245	41,912	16,899	35,237	34,328	27,331	15,348	27,716	11,455	10,444	9,754	12,427	10,692	13,896	23,033	11,881	19,449	42,800	62,854	34,099	55,534	57,861	72,809	35,888	16,213	17,248	15,552	21,309	23,259	16,827	18,339	36,655				1,481,897
				1,720											1,730	1,385		300				430	530				2,761											
10,035	10,501	19,917	28,846	32,643	31,525	41,912	16,899	35,237	34,328	26,718	15,348	27,716	11,455	10,444	9,754	12,427	6,962	12,511	23,033	11,581	19,449	42,800	62,854	33,669	55,004	57,861	72,809	35,888	33,452	17,248	15,552	21,309	23,259	36,827	18,339	36,655			1,448,648
		740							714								1,060						618		1,290	1,320			600			780						
13,988	10,035	10,501	15,197	28,846	32,643	31,525	41,912	16,899	35,237	33,610	26,718	15,348	27,716	11,455	10,444	9,754	12,427	6,962	13,451	23,033	11,581	19,449	42,800	62,236	33,669	53,714	56,941	72,809	35,888	32,852	17,248	15,552	20,529	23,259	36,827	18,339	36,655		1,428,840
		150													710				830				742	4,100		660	440	1,425	500	1,070				430	400	2,725			
1,474	13,988	9,885	10,501	15,197	28,846	32,643	31,525	41,912	16,899	35,237	33,610	26,718	15,348	27,716	11,455	9,754	9,754	12,427	8,132	13,451	23,033	11,581	19,449	42,058	58,136	33,669	52,854	56,103	71,384	35,388	29,782	17,248	15,552	20,529	23,259	36,827	18,804	36,655	
1026930	1012883	1014027	1043725	1038005	1046100	1009844	972,930	925,914	904,745	863,975	828,540	800,820	782,957	751,935	738,615	726,541	712,453	697,996	682,966	661,262	634,984	617,851	594,496	544,111	478,869	440,826	383,460	321,309	247,464	206,207	171,294	151,001	132,598	112,070	88,811	81,984	36,655	0	68,314,328
24,317	16,569	6,535	10,498	8,329	3,615	5,380	5,485	1,936	5,531	1,683	1,404	2,115	3,306	835	3,370	4,134	2,030	6,898	8,253	5,245	5,550	3,308	8,329	7,108	4,304	4,582	4,048	4,461	5,669	5,131	3,045	2,850	-	480	499	2,725	-	0	

in 1903 are small, and those from 1904 to 1936, inclusive, the band from which length of service life was determined, are given in complete detail as to origin.

Reviewing the earlier studies, the writer found that Morey's result was the only one of much value, but the question was then of how much value. The writer dislikes smoothing an observed life table and considers that results of greater probability are obtained by first smoothing mathematically the observed retirement ratios and then making a smoothed life table. To this end, in 1939-1940, a new "Historical Arrangement of Mortality Data" (Table 2 herewith) was prepared, and, in completing this table to show all totals of both vertical and horizontal rows of figures, errors came to light that were corrected in Table 2.

Table 3 gives the observed retirement ratios as originally computed by Morey before the errors just mentioned came to light. These ratios were the ones used by Morey in his studies, and they were also the ones used by the writer in his determination of the life of 6-in. pipe. In Table 3, the total of the observed retirement ratios through the age of 70.5 is 0.44649514, the same as in Table 4.

Trial Curves for Smoothing Observed Ratios. There is thus available a continuous period of exact data for 33 years but with irregular retirement ratios. For these must be substituted a smooth series, to the best degree possible equivalent to them in trend, which can be extended to the age of the last survivor and produce a life table that can be accepted with confidence. This substitution, by the mathematics of probability, takes the form of an equation sometimes of the first degree, usually of the second degree and rarely higher than the third degree.

Being curious to know what variation in results would be yielded by equations of the three powers, the writer tried four curves for smoothing the observed retirement ratios and for each of the four curves made the sum of the readings for ages 0 to 70.5 inclusive equal to 0.44649514, the same as the sum of the observed retirement ratios (as in Table 3) so as to balance plus and minus differences. Each curve was also so chosen that all terms of polynomials have equal effects on the "Drop", or retirement ratio expressed as a percentage, at age 70.5.

TABLE 3.—OBSERVED RETIREMENT RATIOS, 1904-1936

Age, Years	Exposures	Retirements	Observed Retirement Ratios
0	321397	300	.00093342
.5	358890	—	——
1.5	389557	—	——
2.5	405133	—	——
3.5	410534	—	——
4.5	423296	673	.00158990
5.5	418551	70	.00016724
6.5	430776	—	——
7.5	633989	23	.00003627
8.5	400354	—	——
9.5	454153	65	.00014312
10.5	479640	777	.00161996
11.5	509571	—	——
12.5	535154	1727	.00322710
13.5	574691	517	.00089961
14.5	586516	172	.00029325
15.5	616134	2475	.00401698
16.5	648504	609	.00093908
17.5	676894	1253	.00185110
18.5	689925	1642	.00237996
19.5	712895	1321	.00185300
20.5	720029	1125	.00156243
21.5	724500	3832	.00528916
22.5	725717	3431	.00472773
23.5	728176	2732	.00375184
24.5	729674	3676	.00503789
25.5	730121	5495	.00752614
26.5	744990	2257	.00302957
27.5	749384	1550	.00206836
28.5	758197	2991	.00394488
29.5	797117	3733	.00468312
30.5	854672	6921	.00809784
31.5	858997	8338	.00970666
32.5	880711	2487	.00282385
33.5	917122	8823	.00962031
34.5	969887	4885	.00503666
35.5	996404	10380	.01041746
36.5	1026511	10557	.01028435
37.5	1022154	17107	.01673622
38.5	1026530	24417	.02378595

TABLE 3.—(*Continued*)

Age, Years	Exposures	Retirements	Observed Retirement Ratios
39.5	1012883	16569	.01635825
40.5	1014027	8535	.00841693
41.5	1043725	10498	.01005820
42.5	1038005	5229	.00503754
43.5	1046100	3615	.00345569
44.5	1009844	5380	.00532755
45.5	972939	5685	.00584312
46.5	925542	3898	.00421158
47.5	904745	5533	.00611553
48.5	863975	1823	.00211001
49.5	828542	1404	.00169454
50.5	800420	2115	.00264236
51.5	782957	3306	.00422245
52.5	751935	835	.00111046
53.5	739645	3370	.00455623
54.5	726541	4334	.00596525
55.5	712453	2030	.00284931
56.5	697996	6898	.00988257
57.5	682966	8253	.00956352
58.5	663262	5245	.00790788
59.5	634984	5550	.00874037
60.5	617853	4650	.00752606
61.5	593754	7583	.01277128
62.5	544113	7108	.01306346
63.5	478869	4304	.00898784
64.5	440896	4582	.01039247
65.5	383460	4048	.01055651
66.5	323309	4461	.01379794
67.5	247464	5869	.02371658
68.5	206207	5131	.02488276
69.5	171294	3045	.01777645
70.5	151001	2850	.01887404
Sum of 72 terms, ages 0 to 70.5, inclusive (as on Table 4)			.44649514
71.5	132599	—	——
72.5	112070	430	.00383688
73.5	88811	490	.00551733
74.5	51984	2725	.05245630
75.5	36655	—	——
	49071272	303742	.50830565

TABLE 4.—SMOOTHING CURVE FOR OBSERVED RETIREMENT RATIOS—SECOND DEGREE BINOMIAL—S.R.2.

$D = CA + C'A^2 = 0.0106A + 0.000,150,314,771,2\ A^2$

A	D (curve)	D (actual)	Difference +	Difference —	(Difference)^2
0	0	0.093342	——	0.093342	0.008705
0.5	0.005338	0	0.005338	——	.000029
1.5	.016238	0	.016238	——	.000262
2.5	.027439	0	.027439	——	.000751
3.5	.038941	0	.038941	——	.001513
4.5	.050744	.158990	——	.108246	.011664
5.5	.062847	.016724	.046123	——	.002125
6.5	.075251	0	.075251	——	.005670
7.5	.087955	.003627	.084328	——	.007106
8.5	.100960	0	.100960	——	.010201
9.5	.114266	.014312	.099954	——	.010000
10.5	.127872	.161996	——	.034124	.001163
20.5	.280470	.156243	.124227	——	.015376
30.5	.463130	.809784	——	.346654	.120409
40.5	.675854	.841693	——	.165839	.027556
50.5	.918640	.264236	.654404	——	.427716
60.5	1.191490	.752606	.438884	——	.192721
61.5	1.220428	1.277128	——	.056700	.003102
62.5	1.249667	1.306346	——	.056679	.003102
63.5	1.279207	.898784	.380423	——	.144400
64.5	1.309047	1.039247	.269800	——	.072900
65.5	1.339188	1.055651	.283537	——	.080656
66.5	1.369629	1.379794	——	.010165	.000104
67.5	1.400372	2.371658	——	.971286	.942841
68.5	1.431414	2.488276	——	1.056862	1.123600
69.5	1.462758	1.777645	——	.314887	.099225
70.5	1.494402	1.887404	——	.393002	.154449
2520.5	44.649514	44.649514	10.917025	10.917027	13.840883
80.5	1.8274		170.5	6.1770	
90.5	2.1904		180.5	6.8106	
100.5	2.5835		190.5	7.4743	
110.5	3.0067		200.5	8.1680	
120.5	3.4599		210.5	8.8918	
130.5	3.9432		220.5	9.6456	
140.5	4.4566		230.5	10.4296	
150.5	5.0000		236.5	10.9143	
160.5	5.5734				

D=Drop, or Retirement Ratio as a precentage
A=Age in Years
For A=70.5 A^2=4,970.25 A^3=350,402.625

For ages from 0 to 70.5 inclusive:
ΣD = 44.649,514 (Table 4)
ΣA = 2,520.5 (Table 4)
ΣA^2 = 119,297.75 (Table 4)
ΣA^3=6,352,290.125

S.R.1. Straight line.
$D=CA$ $\Sigma D=C\Sigma A$
$44.649,514=C(2520.5)$ $C=0.017,714,546,32$
For A=70.5; D=1.248,876

S.R.2. Second degree binomial. $D=CA+C'A^2$
$\Sigma D=C\Sigma A+C'\Sigma A^2$
$=0.0106\ (2520.5)+0.000,150,314,771,2\ (119,297.75)$
$=26.7173 \quad +17.932,214=44.649,514$

For A=70.5;
$D=0.0106\ (70.5)+0.000,150,314,771,2\ (4970.25)$
$=0.7473 \quad +0.7471 \quad =1.4944$

S.R.3. Cubic. $D=CA+C'A^2+C''A^3$

$C\Sigma A$	=0.008,133,306,883	(2,520.5)	=20.5
$C'\Sigma A^2$	=0.000,115,253,767,9	(119,297.75)	=13.749,514
$C''\Sigma A^3$	=0.000,001,637,204,819	(6,352,290.125)	=10.4
			44.649,514

For A=70.5;

CA	=0.008,133,306,883	(70.5)	=0.573,398
$C'A^2$	=0.000,115,253,757,0	(4,970.25)	=0.572,840
$C''A^3$	=0.000,001,637,204,819	(350,402.625)	=0.573,681
			1.719,919

S.R.4. Parabola. $D=CA^2$
$\Sigma D=C\Sigma A^2=C\ (119,297.75)=44.649,514$
$C=0.000,374,269,539,8$
For A=70.5; D=1.860,213

The record contains annual retirements up to the age of 75.5, but the figures for ages over 70.5 were too small to be of use.

The writer adopted the criterion in selecting each polynomial that each of its terms would have an equal effect on the drop of the curve at the age of 70.5 in order to bring out, for example, in comparing one curve with another, the effect on average service life of

the third degree term of the cubic. To make sure that each curve was properly representative of the scatter that it replaces, another criterion was that the sum of the plus differences should equal the sum of the minus differences and, at the same time, the sum of the squares of the difference was watched. The sums of the differences for the four curves are as follows:

Curve	Sum of Plus Differences Equal to Sum of Minus Differences	Sum of (Difference)^2
S.R.1. Straight line	11.100,765	14.056,184
S.R.2. 2nd Degree	10.917,025	13.840,883
S.R.3. Cubic	11.084,120	14.231,240
S.R.4. Parabola	11.860,062	15.742,408

Figure 1. Figure 1 gives the four trial curves used for smoothing

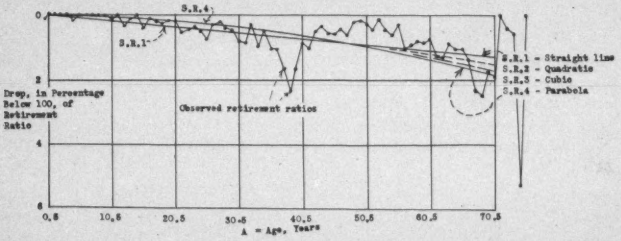


FIG. 1.—FOUR TRIAL CURVES USED FOR SMOOTHING OBSERVED RETIREMENT RATIOS.

the observed retirement ratios for the ages 0.5 to 70.5 years. It also shows the scatter created by the dots representing the observed retirement ratios.

Figure 2. Figure 2 shows the same four trial curves that appear in Figure 1 but extended to 200 years or more of age. Of these four curves, the writer considered S.R.2, the second degree binomial, to be the best one and it has, as may be seen on the preceding page, the smallest sum of the squares of the differences, which is a desideratum. S.R.5 was obtained by Benson by means of the methods of curve fitting that he customarily uses. S.R.6 was obtained by the writer from Benson's figures, by carrying them to greater refinement. The average

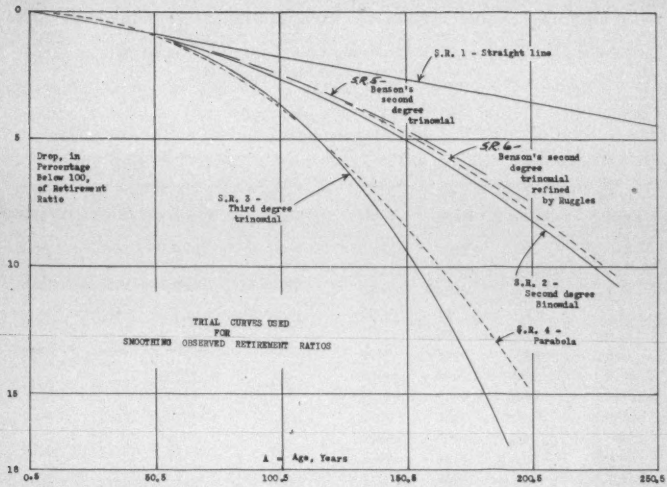


FIG. 2.

service lives resulting from the use of these trial curves for smoothing the observed retirement ratios are:

S.R.1. Straight Line—No result
S.R.2. Second degree—87.1 years
S.R.3. Cubic—83.0 years
S.R.4. Parabola—83.1 years
S.R.5. Benson's curve—Second degree—87.7 years

Table 4. Table 4 gives the values for trial curve S.R.2, the second degree binomial for each year of age up to 236.5 years, or rather the original table does. The table as here presented is skeletonized but shows that the sum of the readings up to 70.5 years agrees with the sum of the observed retirement ratios, namely, 44.649514. It is also seen that the sums of the plus and minus differences are the same up to 70.5 years.

Table 5. Table 5 gives the computation of smoothed life table

TABLE 5.—COMPUTATION OF SMOOTHED LIFE TABLE AND AVERAGE SERVICE LIFE CURVE: SECOND DEGREE BINOMIAL—S.R.2

$D=CA+C'A^2$

Exposures: 1860-1936
Retirements: 1904-1936

Age in Years	Smoothed Retirement Ratios	Smoothed Survival Ratios	Smoothed Life Table	Age in Years	Smoothed Retirement Ratios	Smoothed Survival Ratios	Smoothed Life Table
0	0	1.0000	1.0000	110.5	.0301	.9699	.2671
0.5	0.0001	0.9999	1.0000				
1.5	0.0002	.9998	0.9999	120.5	.0346	.9654	.1928
2.5	.0003	.9997	.9997	130.5	.0394	.9606	.1325
3.5	.0004	.9996	.9994				
4.5	.0005	.9995	.9990	140.5	.0446	.9554	.0865
5.5	.0006	.9994	.9985	150.5	.0500	.9500	.0534
6.5	.0008	.9992	.9979				
7.5	.0009	.9991	.9971	160.5	.0557	.9443	.0309
8.5	.0010	.9990	.9962	170.5	.0618	.9382	.0169
9.5	.0011	.9989	.9952				
10.5	.0013	.9987	.9941	180.5	.0681	.9319	.0087
20.5	.0028	.9972	.9748	190.5	.0747	.9253	.0041
30.5	.0046	.9954	.9402	200.5	.0817	.9183	.0018
40.5	.0068	.9932	.8893	210.5	.0889	.9111	.0008
50.5	.0092	.9908	.8220	220.5	.0965	.9035	.0003
60.5	.0119	.9881	.7404	230.5	.1043	.8957	.0001
70.5	.0149	.9851	.6481	231.5	.1051	.8949	.0001
				232.5	.1059	.8941	.0001
80.5	.0183	.9817	.5492	233.5	.1067	.8933	.0001
90.5	.0219	.9781	.4492	234.5	.1075	.8925	.0001
				235.5	.1083	.8917	.0001
100.5	0.0258	0.9742	0.3536	236.5	.1091	.8909	.0001
							0.0000
							88.0685
					Less		1.
							87.0685

and average service life for exposures from 1860 to 1936 and retirements from 1904 to 1936. This table, also based on S.R.2, the second degree binomial smoothing curve, takes the smoothed retirement ratios from Table 4. At age 236.5, there is no longer any change in the fourth decimal in the life table, and the average service life is found to be 87.0685. The deduction of *1* at the foot of the life table is due to having only 0.5 years as the first period in the table and this deduction is obtained by adding ¾ of the first reading to ¼ of the second reading.

TABLE 6.—SUMMARY OF MORTALITY DATA FOR COMPUTATION OF OBSERVED LIFE TABLE
LINEAR FEET OF PIPE

Age in Years	Exposures	Retirements	Observed Retirement Ratios	Observed Survival Ratios	Observed Life Table
0.0	321397	300	0.00093	0.99907	1.00000
0.5	358890	—	——	1.00000	0.99907
1.5	389557	—	——	1.00000	0.99907
2.5	405133	—	——	1.00000	0.99907
3.5	410534	—	——	1.00000	0.99907
4.5	423296	673	0.00159	0.99841	0.99907
5.5	418551	70	0.00017	0.99983	0.99748
6.5	430776	—	——	1.00000	0.99731
7.5	436599	23	0.00005	0.99995	0.99731
8.5	440354	—	——	1.00000	0.99726
9.5	454153	65	0.00014	0.99986	0.99726
10.5	479640	777	0.00162	0.99838	0.99712
11.5	509571	—	——	1.00000	0.99550
12.5	535154	1727	0.00323	0.99677	0.99550
13.5	574691	517	0.00090	0.99910	0.99228
14.5	586516	172	0.00029	0.99971	0.99139
15.5	616134	2475	0.00402	0.99598	0.99110
16.5	648504	609	0.00094	0.99906	0.98712
17.5	676894	1253	0.00185	0.99815	0.98619
18.5	689925	1642	0.00238	0.99762	0.98437
19.5	712895	1321	0.00185	0.99815	0.98203
20.5	720110	1198	0.00166	0.99834	0.98021
21.5	724427	3759	0.00519	0.99481	0.97858
22.5	725717	3431	0.00473	0.99527	0.97350
23.5	728176	2732	0.00375	0.99625	0.96890
24.5	729674	3676	0.00504	0.99496	0.96527

TABLE 6.—(*Continued*)

Age in Years	Exposures	Retirements	Observed Retirement Ratios	Observed Survival Ratios	Observed Life Table
25.5	730124	5495	0.00753	0.99247	0.96041
26.5	744990	2257	0.00303	0.99697	0.95318
27.5	749384	1550	0.00207	0.99793	0.95029
28.5	758197	2991	0.00394	0.99606	0.94832
29.5	797117	3733	0.00468	0.99532	0.94458
30.5	854672	6921	0.00810	0.99190	0.94016
31.5	858665	8338	0.00971	0.99029	0.93254
32.5	880711	2616	0.00297	0.99703	0.92349
33.5	917121	8823	0.00962	0.99038	0.92075
34.5	969887	4885	0.00504	0.99496	0.91189
35.5	996404	10380	0.01042	0.98958	0.90729
36.5	1026511	10557	0.01028	0.98972	0.89783
37.5	1022154	17107	0.01674	0.98326	0.88860
38.5	1026530	24417	0.02379	0.97621	0.87117
39.5	1012883	16569	0.01636	0.98364	0.85044
40.5	1014027	8535	0.00842	0.99158	0.83653
41.5	1043725	10498	0.01006	0.98994	0.82949
42.5	1038005	5229	0.00504	0.99496	0.82115
43.5	1046100	3615	0.00346	0.99654	0.81701
44.5	1009844	5380	0.00533	0.99467	0.81418
45.5	972939	5485	0.00564	0.99436	0.80984
46.5	925542	3898	0.00421	0.99579	0.80527
47.5	904745	5533	0.00612	0.99388	0.80187
48.5	863975	1823	0.00211	0.99789	0.79696
49.5	828542	1404	0.00169	0.99831	0.79527
50.5	800420	2115	0.00264	0.99736	0.79393
51.5	782957	3306	0.00422	0.99578	0.79183
52.5	751935	835	0.00111	0.99889	0.78848
53.5	739645	3370	0.00456	0.99544	0.78760
54.5	726541	4334	0.00597	0.99403	0.78401
55.5	712453	2030	0.00285	0.99715	0.77933
56.5	697996	6898	0.00988	0.99012	0.77711
57.5	682966	8253	0.01208	0.98792	0.76943
58.5	663262	5245	0.00791	0.99209	0.76014
59.5	634984	5550	0.00874	0.99126	0.75413
60.5	617853	3908	0.00633	0.99367	0.74754
61.5	594496	8325	0.01400	0.98600	0.74281
62.5	544113	7108	0.01306	0.98694	0.73241

TABLE 6.—(*Continued*)

Age in Years	Exposures	Retirements	Observed Retirement Ratios	Observed Survival Ratios	Observed Life Table
63.5	478869	4304	0.00899	0.99101	0.72284
64.5	440896	4582	0.01039	0.98961	0.71634
65.5	383460	4048	0.01056	0.98944	0.70889
66.5	323309	4461	0.01380	0.98620	0.70140
67.5	247464	5869	0.02372	0.97628	0.69172
68.5	206207	5131	0.02488	0.97512	0.67531
69.5	171294	3045	0.01778	0.98222	0.65851
70.5	151001	2850	0.01887	0.98113	0.64680
Sub-totals	48492183	300026	0.44903	71.55097	63.21010
71.5	132599	—	——	1.00000	0.63459
72.5	112070	430	0.00384	0.99616	0.63459
73.5	88811	490	0.00552	0.99448	0.63215
74.5	51984	2725	0.05246	0.94754	0.62866
75.5	36655	—	——	1.00000	0.59568
Totals	48914302	303671	0.51085	76.48915	66.33577

Table 6. This table, superseding Table 3 of 1938, gives exposures and retirements and the resulting observed life table after the incorporation of the corrections found to be necessary and previously referred to.

Later Result Obtained by Benson. Following the derivation by the writer in 1939 of 87.1 years as the average service life of the 6-in. pipe, in 1940 C. B. Benson, Principal Statistician (Engineering) of the Public Service Commission, at the request of the writer, made a determination for the same band of years, and using the corrected exposures and retirements of Table 6. He smoothed the observed retirement ratios by use of a second degree curve, shown as S.R.5 in Figure 2, and obtained an average service life for the 6-in. pipe of 87.7 years. The writer reviewed Benson's computations and found that his second degree smoothing curve is a trinomial with the formula:

$$D=0.036,663+0.010,401\ A+0.000,134\ A^2$$

Where A is the age in years and D is the retirement ratio as a percentage. The "terminal value" of D, for A=70.5, is:

	0.036,663	= 2.5%
+0.010,401 (70.5)	= 0.773,270.5	= 51.1%
+0.000,134 $(70.5)^2$	= 0.666,013,5	= 46.4%
	1.435,947	100.0%

The writer then carried to a little greater refinement the computations from the formulas in Benson's "Notes on Curve Fitting" and obtained:

$$D=0.051,835+0.009,350+0.000,148\ A^2$$

This gives a terminal value of D, for A=70.5, of:

	0.051,835
+0.009,350 (70.5)	= 0.659,175
+0.000,148 $(70.5)^2$	= 0.735,597
	1.446,607

This formula is shown as S.R.6 in Figure 2 and is very close to S.R.2, the second degree binomial obtained by the writer in 1939 and preferred by him over the cubic and the parabola. The formula of S.R.2 is:

$$D=0.010,6\ A+0.000,150\ A^2.$$ This has no constant,

which seems preferable to the writer, and, as was shown in Table 4, before it was skeletonized, each term is 50 per cent at age 70.5.

0.0106 (70.5)	= 0.7473
0.000,150 (4970.25)	= 0.7455
	1.4928

Table 7. Table 7 gives the life expectancy. The figures in the second column for survivors at beginning of age interval are taken from the "Life Table" column of Table 5. The resulting probable life curve as given in the last column is plotted in Figure 3.

Table 8. This table tests the fit of the smoothing curve S.R.2 by age of retirement. Exposures, in linear feet of pipe for each age, as given in Table 8 are taken from Table 2. The smoothed retirement ratios are as obtained from S.R. 2 and as given in Table 5. Retirements indicated by the Smoothed Retirement Curve, as shown in the last column, are plotted in Figure 4 for comparison with the observed retirements.

TABLE 7.—LIFE EXPECTANCY

Age Interval, Years	Survivors at Beginning of Age Interval, %	Service During Age Interval, %	Remaining Service at Beginning of Age Interval, %—Years	Expectancy at Beginning of Age Interval, Years	Probable Life at Beginning of Age Interval, Years
0 - 0.5	100.00	50.00	8706.85	87.07	87.07
0.5- 1.5	100.00	99.995	8656.85	86.57	87.07
1.5- 2.5	99.99	99.98	8556.855	85.58	87.08
2.5- 3.5	99.97	99.955	8456.875	84.59	87.09
3.5- 4.5	99.94	99.92	8356.92	83.62	87.12
4.5- 5.5	99.90	99.875	8257.00	82.65	87.15
5.5- 6.5	99.85	99.82	8157.125	81.69	87.19
6.5- 7.5	99.79	99.75	8057.305	80.74	87.24
7.5- 8.5	99.71	99.665	7957.555	79.81	87.31
8.5- 9.5	99.62	99.57	7857.89	78.88	87.38
9.5- 10.5	99.52	99.465	7758.32	77.96	87.46
10.5- 11.5	99.41	99.345	7658.855	77.04	87.54
20.5- 21.5	97.48	97.345	6673.26	68.46	88.96
30.5- 31.5	94.02	93.805	5714.39	60.78	91.28
40.5- 41.5	88.93	88.63	4798.245	53.96	94.46
50.5- 51.5	82.20	81.82	3941.30	47.95	98.45
60.5- 61.5	74.04	73.60	3159.05	42.67	103.17
70.5- 71.5	64.81	64.325	2464.055	38.02	108.52
80.5- 81.5	54.92	54.415	1865.12	33.96	114.46
90.5- 91.5	44.92	44.43	1366.07	30.41	120.91
100.5-101.5	35.36	34.905	965.25	27.30	127.80
110.5-111.5	26.71	26.31	655.795	24.55	135.05
120.5-121.5	19.28	18.945	426.94	22.14	142.64
130.5-131.5	13.25	12.99	265.465	20.04	150.54
140.5-141.5	08.65	8.455	157.075	18.16	158.66
150.5-151.5	05.34	5.205	88.12	16.50	167.00
160.5-161.5	03.09	3.005	46.795	15.14	175.64

TABLE 7.—(*Continued*)

Age Interval, Years	Survivors at Beginning of Age Interval, %	Service During Age Interval, %	Remaining Service at Beginning of Age Interval, %—Years	Expectancy at Beginning of Age Interval, Years	Probable Life at Beginning of Age Interval, Years
170.5-171.5	01.69	1.64	23.435	13.87	184.37
180.5-181.5	00.87	0.84	10.985	12.63	193.13
190.5-191.5	00.41	0.395	4.835	11.79	202.29
200.5-201.5	0.18	0.175	1.99	11.06	211.56
210.5-211.5	0.08	0.075	0.74	9.25	219.75
220.5-221.5	0.03	0.03	0.245	8.17	228.67
230.5-231.5	0.01	0.01	0.065	6.50	237.00
231.5-232.5	0.01	0.01	0.055	5.50	237.00
232.5-233.5	0.01	0.01	0.045	4.50	237.00
233.5-234.5	0.01	0.01	0.035	3.50	237.00
234.5-235.5	0.01	0.01	0.025	2.50	237.00
235.5-236.5	0.01	0.01	0.015	1.50	237.00
236.5-237.5	0.01	0.005	0.005	0.50	237.00
	8806.85	8706.850			

(As at the end of the Life Table, Table 5)

Findings. As mentioned at the outset, it seemed preferable to the writer to confine these studies to pipe in the City System, to installations in the years 1860 to 1936, and to removals in the years 1904 to 1936. By doing this, the studies were limited to a long period of accurate data. The installations and removals varied tremendously year by year, and, due to their great irregularity, it seemed best to base the studies on as long a period of years as possible. Also, as mentioned earlier, close to 25 per cent of the 6-in. pipe installed had been removed by the end of 1936 which is a satisfactorily high percentage for a study of this kind.

In a long period of years, the trends representing the rates of removals sometimes change from one part of the period to a later

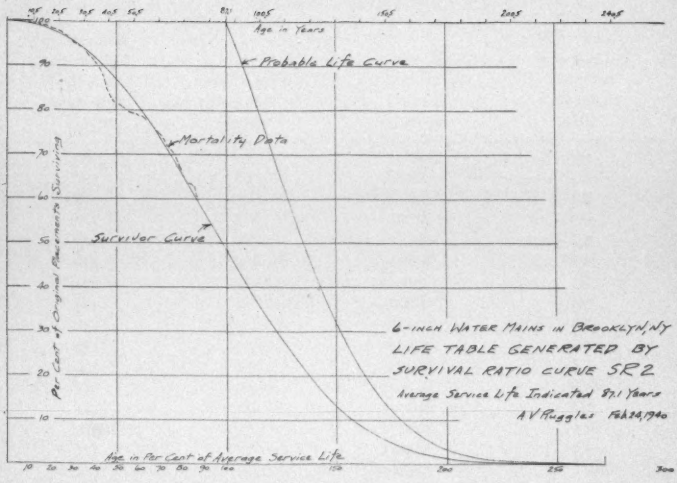

Age in Years
Probable Life Curve
Mortality Data
Survivor Curve
Per Cent of Original Placements Surviving
6-INCH WATER MAINS IN BROOKLYN, NY
LIFE TABLE GENERATED BY
SURVIVAL RATIO CURVE SR2
Average Service Life Indicated 87.1 Years
A.V. Ruggles Feb 24, 1940
Age in Per Cent of Average Service Life

FIG. 3.

part, and, when determinations of average service life are made from a short band of years and the total percentage of removals is small, it is hard in some cases to have full confidence in the results obtained by customary statistical methods. Here, however, the conditions are favorable. Nevertheless, being based on a long period of time, it is advisable as in every such study to learn as much as possible about the important causes and effects that had brought about changes in trends of rates of removals.

The writer feels that the average service life of 87.1 years given by the use of S.R.2 is a good value. Benson's S.R.5 gives 87.7 and S.R.6 looks as if would give 87.4 or 87.3. Morey's value of 90.1 is not far away, although he smoothed for only every tenth year. He seems to have made a creditable application of the Gompertz-Makeham formula which the writer dislikes, however, as illogical in form.

Effect or Pipe Replacements of Construction of Subways in Brooklyn. Throughout all the studies by the Water Bureau staff of

TABLE 8.—TEST OF FIT OF SMOOTHING CURVE S.R.2 BY AGE AT RETIREMENT

Age in Years	Exposures	Smoothed Retirement Ratios	Retirements Indicated by Smoothed Retirement Curve
0	321397	0	
0.5	358890	0.0001	36
1.5	389557	2	78
2.5	405133	3	122
3.5	410534	4	164
4.5	423296	5	212
5.5	418551	6	251
6.5	430776	8	345
7.5	436599	9	393
8.5	440354	10	440
9.5	454153	11	500
10.5	479640	13	624
11.5	509571	14	713
12.5	535154	16	856
13.5	574691	17	977
14.5	586516	19	1114
15.5	616134	20	1232
16.5	648504	22	1427
17.5	676894	23	1557
18.5	689925	25	1725
19.5	712895	26	1854
20.5	720110	28	2016
21.5	724427	30	2173
22.5	725717	31	2250
23.5	728176	33	2403
24.5	729674	35	2554
25.5	730124	37	2701
26.5	744990	39	2905
27.5	749384	41	3072
28.5	758197	42	3184
29.5	797117	44	3507
30.5	854672	46	3931
31.5	858665	0.0048	4122
32.5	880711	0.0050	4404
33.5	917121	52	4769
34.5	969887	54	5237
35.5	996404	57	5680
36.5	1026511	59	6056
37.5	1022154	61	6235

TABLE 8.—(*Continued*)

Age in Years	Exposures	Smoothed Retirement Ratios	Retirements Indicated by Smoothed Retirement Curve
38.5	1026530	63	6467
39.5	1012883	65	6584
40.5	1014027	68	6895
41.5	1043725	70	7306
42.5	1038005	72	7474
43.5	1046100	75	7846
44.5	1009844	77	7776
45.5	972939	0.0079	7686
46.5	925542	82	7589
47.5	904745	84	7600
48.5	863975	87	7517
49.5	828542	89	7374
50.5	800420	92	7364
51.5	782957	94	7360
52.5	751935	0.0097	7294
53.5	739645	0.0100	7396
54.5	726541	02	7411
55.5	712453	5	7481
56.5	697996	8	7538
57.5	682966	11	7581
58.5	663262	13	7495
59.5	634984	16	7366
60.5	617853	19	7352
61.5	594496	22	7253
62.5	544113	25	6801
63.5	478869	28	6130
64.5	440896	31	5776
65.5	383460	34	5138
66.5	323309	37	4429
67.5	247464	40	3464
68.5	206207	43	2949
69.5	171294	46	2501
70.5	151001	49	2250
71.5	132599	53	2029
72.5	112070	56	1748
73.5	88811	59	1412
74.5	51984	62	842
75.5	36655	0.0166	608
			304901

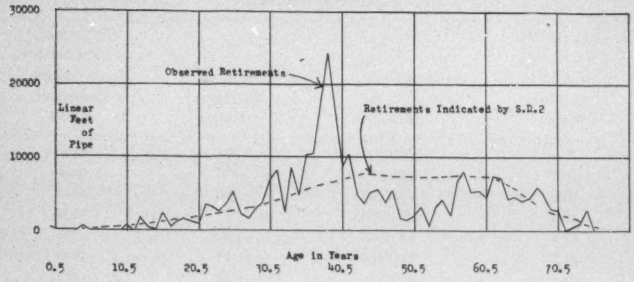


FIG. 4.—TEST OF FIT OF SMOOTHING CURVE S.R.2 BY AGE AT RETIREMENT.

Brooklyn history, the question kept recurring as to how much or how little the rate of retirement of water mains in Brooklyn was affected by the construction of the subways in that borough. The writer knows from experience on constructoin of subways in New York City that when a subway cut extends from house front to house front, the structures of the utilities have to get out of the way temporarily, which means sometimes for four years. Service throughout the period of the contracts is kept up but sometimes by temporary use of less permanent materials. The disruption of water mains, however, does not extend very far to the sides of the path of the subway work. As mentioned previously, most of the 6-in. pipe removed is replaced with 8-in. and this has an effect on the average service life of either one of those two sizes of pipe in Brooklyn.

The writer obtained some figures on costs and lengths of all the subway lines built in Brooklyn, these figures being furnished by Jesse B. Snow, Chief Engineer of the Board of Transportation. The writer took some liberties with these figures as received but developed essentially the number of miles of subway built each year from 1910 to 1934 inclusive.

Figure 5 shows the following three curves:

1. Installations of 4-, 6-, 8- and 12-in pipe in the "City System";
2. Removals of 6-in. pipe in the "City System"; and
3. Miles of subway built each year in Brooklyn.

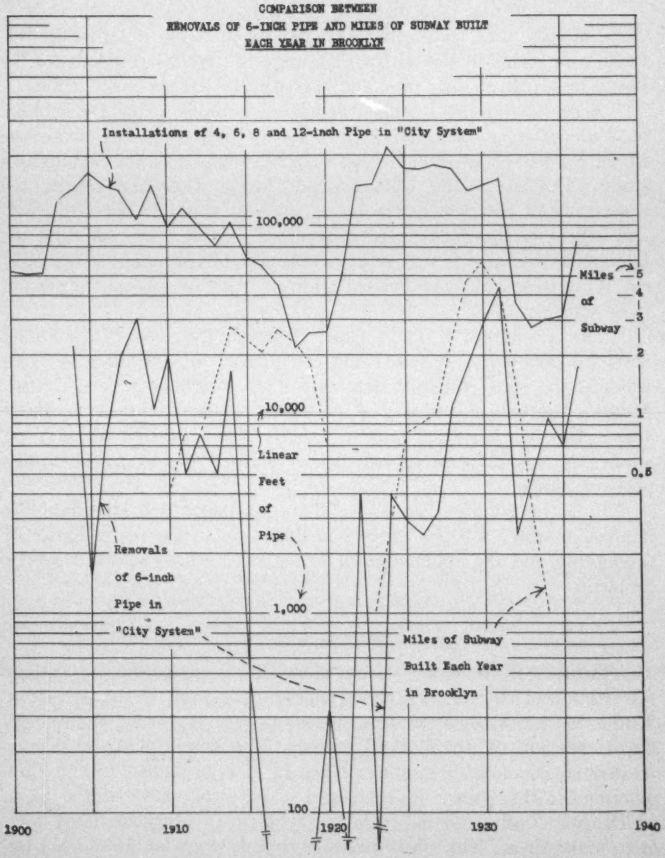

COMPARISON BETWEEN
REMOVALS OF 6-INCH PIPE AND MILES OF SUBWAY BUILT
EACH YEAR IN BROOKLYN
Installations of 4, 6, 8 and 12-inch Pipe in "City System"
100,000
10,000
1,000
100
Linear
Feet
of
Pipe
Removals
of 6-inch
Pipe in
"City System"
Miles
of
Subway
5
4
3
2
1
0.5
Miles of Subway
Built Each Year
in Brooklyn
1900
1910
1920
1930
1940

FIG. 5.

The lengths of pipe installed and removed year by year vary so tremendously that these plottings had to be made logarithmic vertically. It seems to the writer that there is some correspondence between removals of 6-in. pipe and activity in subway construction.

Acknowledgments. Acknowledgment is made to the Department of Water Supply, Gas and Electricity for preparing and furnishing to the Public Service Commission's engineers the data for making this study. The late Water Commissioner Joseph Goodman contributed generously of his time to the preparation of the data through 1932, and others in the department coöperated similarly in compiling the figures for the later years. Acknowledgment is also made to the present Water Commissioner Patrick Quilty for his permission to present these figures.

The late Arthur H. Pratt, Chief Hydraulic Engineer of the Public Service Commission, initiated and encouraged these studies by engineers of the staff of the Water Bureau, of which he was in charge. Milo R. Maltbie is Chairman of the Public Service Commission, under whose direction a special staff of experts was organized to carry on studies of this kind on service life of many types of public utility property units.

It is the hope of the writer that this paper will stimulate the interest of water works engineers in the study of the mathematics of probability and the application of statistical methods to water works problems.

Discussion

Thomas H. Wiggin.* I am glad of the opportunity to explain the relation of this very excellent paper to the work of the American Water Works Association Committee on Survival and Retirement Experience with Water Works Facilities. The American Water Works Association Committee is not engaged in making studies of the kind described in this paper; it is engaged in collecting the material from which such studies can be made in any form in which anybody sees fit to make them. The mathematical method which has been used by the insurance people for so long, and which was adapted for telephone

*Consulting Engineer, New York, N. Y.

property by some engineers and accountants and more recently has begun to be used by some for water supply and other physical property, is an interesting one and offers a mathematical way by which one can make a prediction as to the ultimate life of plant. But on the other hand, when there is only a comparatively short life experience for a property, much of which is evidently going to last to a great age, extrapolation by mathematical or other means must always be subject to a good deal of doubt and other methods may be preferable.

It would be well I think to caution everybody who seeks to use these methods to consider carefully the peculiarities of different plants. For example, one plant may have a corrosive condition of ground which would tend to cause depreciation much more rapidly than others. If one should undertake to apply a survivor curve such as the one described in the author's paper relating to the Brooklyn 6-in. cast-iron pipe to pipe in such corrosive ground, he would fall into error. On the other hand, if he should undertake to apply this curve to some smaller community where a 6-in. pipe would be an adequate size for long years to come, and where the policy caused by insurance conditions—i.e., for protection from fire—would not be so drastic, he would be unduly high in his depreciation allowance. Also the many pipe changes required by subway construction in this case had quite a material effect.

In other words, there are a good many individual conditions that have to be considered in each study of this kind, and we cannot hope to get a composite average life for 6-in. pipe or for 8-in. pipe or for any other size and then apply it to every situation by a rule of thumb process, which engineers who have not the time to study a problem of this kind in detail are too prone to do. Every case should be considered separately and not as another case like the average case.

WILLIAM W. BRUSH.* I do not expect to give much time to discussing the mathematical or statistical methods used in analyzing 6-in. pipe retirement in Brooklyn, N. Y. You may be interested in what I can recall about the causes of retirement of this pipe.

I was largely brought up among these pipes, had a great deal to

*Editor, Water Works Engineering, New York, N. Y.

do with the removal of many miles of them, and my recollection of the condition of the pipe retired might be helpful in connection with a consideration of the curves presented in Mr. Ruggles' paper. So far as the curves are concerned and the determination made, I believe they are extremely helpful in giving us a true picture of what has happened and what is likely to happen in a distribution system where the pipe removed is affected by the conditions of the past. These determinations also are influenced by the causes for removal that have existed in both the immediate and the more distant past.

In Brooklyn, where I started as a junior engineering assistant in 1894, a somewhat unusual situation existed. At that time, the distribution system was under the jurisdiction of a water purveyor who was not a technically trained man and had no technical staff. I recall very distinctly one of his assistants telling me that, for many years, the basis upon which the distribution system of Brooklyn was laid out was an attempt to keep the water in the mains, as the amount of water available was constantly becoming inadequate to meet the demands. Therefore, to avoid a high consumption, an effort was made to prevent the water coming out of the mains too freely.

The service pipes and the plumbing in the houses were largely of lead, and this lead pipe, to my personal knowledge, showed a high flow coefficient that was affected very slightly over a period of, let us say, seventy years. I lived for about thirty-five years in houses in Brooklyn served with lead pipe and the faucet flows were satisfactory. You will notice that recently a lead alloy pipe has been developed which can be used with much thinner walls.

When the engineering force of the Brooklyn Water Bureau was placed in charge of the distribution system following some rather trying situations when the water supply was quite inadequate at the beginning of this century, I personally went out with men from the office and opened up valves between the intermediate and low services to get enough water to give the firemen some chance of putting out a large fire a block from the City Hall. That area was served with 6-in. pipe, and even at that time, many of the pipes had a coefficient C, in the Williams and Hazen formula, of fifty, sixty or seventy. Some years later, pipes in the Brooklyn system showed C to be less than twenty due to tuberculation. We tried cleaning some Brooklyn pipe

at the beginning of the century—I think about 1903—and in three years, the conditions had gone back so nearly to those obtaining before cleaning that it was quite obvious that cleaning the pipe without treating the water was a hopeless procedure so far as maintaining capacity.

We then started in to replace many of the 6-in. pipes, and this action was accelerated very decidedly by the report of the engineers of the National Board of Fire Underwriters, who recommended 8-in. pipe as the minimum size. I have often thought that it is very doubtful if the 8-in. pipe would have been recommended as the minimum size had we used a lining in the pipe effectively to protect the iron from corrosion and thus maintain the original carrying capacity of the main. Today, there is no question in my mind but that the 8-in. pipe was the desirable minimum size under the conditions existing when we adopted it in New York and Brooklyn.

It is true, as Mr. Ruggles points out in his curves, that when the subways were extended, the replacement of the small pipe in Brooklyn was accelerated. It was then our policy, when a pipe was exposed and we could take it out without the expense of excavation or of relaying the pavement, to replace the existing pipe with a larger pipe, if the carrying capacity of the existing pipe was considered to be inadequate.

Since about 1925, we have used in Brooklyn cement lined pipe, but prior to that, we used dipped pipe, and you know the answer there as to rapid tuberculation with an active water.

I will add the caution that Mr. Wiggin has given, not to apply the figures that you get from one system to another system without very careful thorough consideration of the factors that affect the retirement of pipe in both systems. In Brooklyn, if the pipe had originally been protected by a coating that would have prevented tuberculation for one or two hundred years, the probabilities are that most of the pipes represented on the curve would still be in the ground and giving satisfactory service.

I remember that, in 1895 or 1896, we were considering installing a steel main, and then assumed thirty-five years as the life of the steel main. This 60-in. steel main was laid around Ridgewood Reservoir in 1896. That is forty-five years ago, and I do not recall any repairs being made on that main during all these years. It was not

particularly well protected by the asphalt coating but as far as I know, it is in a condition to last a good many years longer.

Around the end of the century, we considered fifty to seventy-five years the life of cast-iron pipe, but as you can see, the indications are that even the uncoated and tar-dipped pipe will last much longer. Mr. Ruggles has made computations which show that the pipe will probably have an average life of eighty-seven years.

I thought it would be interesting to bring out as far as I could, the reasons why we took out these 6-in. pipes and why a good many of the 8-in. pipes will probably be taken out in time because most of the early Brooklyn pipes were laid without adequate protective coating.

PERCY R. SANDERS.* I would like to ask Mr. Brush, what was done with the pipe that was removed.

MR. BRUSH. When the pipe was pulled out, it was smashed and sold for scrap iron. It did not pay to do anything with it. A great deal of the pipe we took out was laid before protective coatings were available. We took out many miles in 1902 and subsequent years. Today, probably some of the pipes removed might be economically cleaned, coated with a cement lining, with a protective seal coat of asphalt over the lining, and put back in use.

The early pipes, which I think very properly were not included by Mr. Ruggles, and which were in the original Brooklyn system, were cast on the side and therefore were of uneven wall thickness. The lack of metal in the thin side of the pipe made it impractical to tap the thin and partially oxidized pipe wall and hold the tap satisfactorily in this thin wall. The later pipes that were cast vertically, subsequent to about 1860, generally speaking have plenty of metal left in the wall so that such pipe could be cleaned and used over again.

MR. SANDERS. The reason I speak of it, Mr. Brush, is that we replaced about 1,600 ft. of 6-in. last year with 10-in. pipe, and when we cleaned the pipe removed, we found the surface of the iron was clean and one could see the original coating. However, we did not use the pipe again without having it lined.

MR. BRUSH. In Brooklyn, the pipe, after being in use for about

*Superintendent, Concord, N. H.

sixty years, showed an average of approximately, as I recall it, one-sixteenth of an inch of iron that was gone by oxidization completely around the circle. I remember we took out a 30-in. pipe and measured the depth of oxidization. Where the iron had been attacked we had virtually lost everything except the carbon. Some of the individual pits were as much as a quarter of an inch in depth.

We had one group of pipes that was laid in 1864, cast in the Florence, N. J., Foundry, these pipes were taken out about sixty years later and found to be in as good condition as when they were laid, except that occasionally, apparently there had been a scratch in the coating caused by a sharp tool and tuberculation had formed along the scratch line. It seemed to me that probably the cause of these pipes being nearly free from tubercules was that the pipes were not cleaned well in the foundry, that quite a good deal of sand had adhered to the castings, and when dipped, the thickness of the tar coating was materially greater.

MR. SANDERS. Do you happen to know when they stopped casting pipe horizontally?

MR. BRUSH. About 1860.

A STATISTICAL METHOD FOR THE ESTIMATION OF AVERAGE SERVICE LIFE

BY C. BEVERLEY BENSON*

[*Read September 25, 1941.*]

The purpose of this paper is to illustrate a method for estimating the average service life of physical property from a study of the statistical records of retirements and additions. At first thought, it might seem that no very difficult problem is involved, since one could simply find the average age at which retirements have been made in the past. While this method will indeed yield the correct average life for the property actually retired, it will not yield a reliable estimate for the entire group being studied, unless the records contain retirements from all possible ages up to the ultimate limit of life, and even then unless growth can be properly discounted, etc.

Suppose, for example, that a complete record were available today of the deaths at each age from the group of persons born in 1900. The average age at death from this group would obviously be less than 41 years and clearly could not be the final average life for the group born in 1900. The data on the 6-in. cast-iron water mains of Brooklyn, discussed by Mr. Ruggles in the preceding paper of this JOURNAL, reveal that the average age of retirements in the period 1904 to 1936 from all years of placement back to 1860 was about 44.5 years. Since the average age of the survivors at the end of 1936 had already reached 49.5 years, it is obvious that the average age of past retirements is of little significance by itself in estimating the service life of this property group.

Except for a few kinds of short-lived property, like automobiles, most of the physical property of public utilities has not been in use long enough to give us completed generations with which to work. It becomes necessary, therefore, to devise a method for analyzing past experience of partly completed generations and extending the trends thus established. It follows, as a matter of course, that such a

*Principal Statistician (Engineering), New York Public Service Commission.

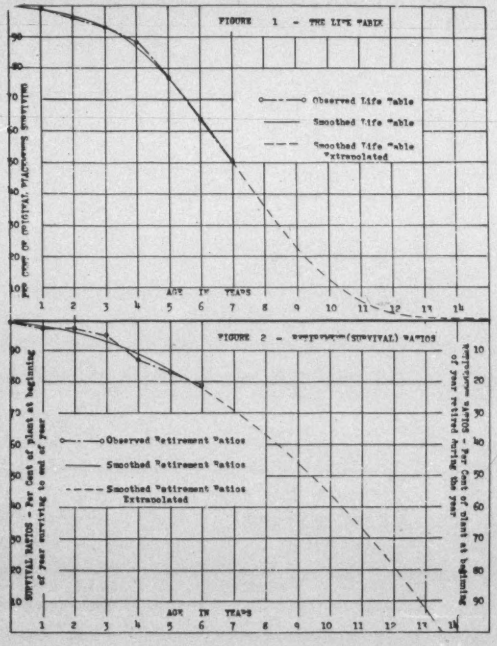
Life Table

Age (1)	Observed Life Table (Number exposed to the risk of retirement at beginning of the year) (2)	Observed Retirement Ratios (Proportion of col. 2 retired during the year) (3)	Number retired during the year (4) = (2) x (3)	Number surviving at end of year (5) = (2) − (4)		Smoothed Retirement Ratios (6)	Smoothed Survival Ratios (7) = 1.00 − (6)	Smoothed Life Table (8) = Previous value of (8) x corresponding (7)
0	1000.0	0.01	10.0	990.0		0.01	0.99	1.0000
1	990.0	0.03	29.7	960.3		0.02	0.98	0.9900
2	960.3	0.03	28.8	931.5		0.04	0.96	0.9702
3	931.5	0.05	46.6	884.9		0.07	0.93	0.9314
4	884.9	0.13	115.0	769.9		0.11	0.89	0.8662
5	769.9	0.17	130.9	639.0		0.16	0.84	0.7709
6	639.0	0.21	134.2	504.8		0.22	0.78	0.6476
7	504.8	—	—	—	Extrapolated Values	0.29	0.71	0.5051
8	—	—	—	—		0.37	0.63	0.3586
9	—	—	—	—		0.46	0.54	0.2259
10	—	—	—	—		0.56	0.44	0.1220
11	—	—	—	—		0.67	0.33	0.0537
12	—	—	—	—		0.79	0.21	0.0177
13	—	—	—	—		0.92	0.08	0.0037
14	—	—	—	—		—	—	0.0003
15	—	—	—	—		—	—	0.0000
						Total		7.4633
						Less		.5000
						Average Service Life		6.9633

method must deal not only with retirements but with survivors as well.

The first device that suggests itself for this purpose is the actuarial life table. Suppose, for example, that it is known that of 1,000 placements in a certain year 990 were surviving at the end of the year, 970 at the end of the next year, 931 at the end of the next year, and so on to 505 surviving at the end of the sixth year, as shown in Column 5 of the accompanying table. This statement of survivors at each age is called the observed life table. A graph of this life table on a percentage basis is shown in Figure 1.

This observed life table may be completed by extending it by eye or by some mathematical process, and an estimate of average



service life may be made from the area under the curve. There are two objections to this plan. In the first place, the equation of the life table is extremely complex and difficult to fit to the observed data. In the second place, the various entries in the observed life table are not independent of each other since they are calculated in a chain series (Columns 4 and 5). This is particularly important, as will appear later, since our observations may often not all be based upon the same group of starters.

On the other hand, the retirement ratios (Column 3) constitute a frequency function with a higher degree of independence since the retirement ratio at one age is not necessarily influenced by that at another age. The circles in the graph in Figure 2 represent these retirement ratios. It is a comparatively simple series to smooth mathematically. By extending the trend so established, estimates can be made of retirement ratios for ages greater than those for which data are available and the life table can be completed.

In actual practice, we seldom have the entire history from the beginning even on an uncompleted generation, and, when we do have such data, it is not usually wise to draw conclusions from the experience of one generation.

One alternative to this plan is to take a cross-section of the experience of all surviving generations. For example, if a study be made at the end of 1941, the deaths in 1941 among human beings born in 1940 will give the death rate for the first year of life; the deaths in 1941 among those born in 1939 will give the death rate for the second year of life; the deaths in 1941 among those born in 1921 will give the death rate for the twentieth year of life, and so on. Thus we will have a series of death rates at all ages represented by survivors.

It is usually not desirable to use a series based upon the experience of a single calendar year when health may have been affected by an epidemic or by unusual climatic conditions. It is therefore customary to use a *band* of calendar years. For example, the death rates (or retirement rates if physical property is being studied) may be calculated from an average of three years of experience. Thus, the death rate for the first year may be calculated by using the deaths in 1941 from 1940 births, in 1940 from 1939 births, in 1939 from 1938 births. The death rate for the twentieth year of life would similarly

be calculated by using the deaths in 1941 from 1921 births, in 1940 from 1920 births, and in 1939 from 1919 births, and so on. This wider band of experience is likely to yield a series of death rates (or retirement rates) of greater statistical stability.

Mr. Ruggles in his paper presents a band for the 6-in. cast-iron water mains of Brooklyn with retirements in the years 1904 to 1936 inclusive from placements back to 1860. Thus, he has 33 items at each age up to 43½ years, 32 items at age 44½, and so on down to one item at age 75½.

While the series thus established from a band of experience may not be exactly representative of any single generation, it does give us a composite cross-section of what has been happening in recent years. That is generally more important than experience of the remote past. For example, the conditions under which pipe laid in 1860 was removed in 1870 were very different from those under which pipe laid in 1930 was removed in 1940. For present purposes, the more recent experience is of greater value.

A great advantage of the band analysis, as it is called, is that it does not require the complete history of gross additions and retirements from early years whose records may be unavailable or made available only at great cost. If the age distribution of presently surviving property can be determined and the retirements for a band of recent years can be aged, the mortality sheet (see Mr. Ruggles' paper) can be constructed backwards by adding the retirements to the corresponding exposures until the data become too difficult to obtain or too sparse to be statistically reliable. The width of the band needed varies with the life of the property being studied as well as with other factors and is a matter involving, to some extent, the judgment of the engineer. In some cases, I have had remarkably good results from a three-year band for wood poles, while in other cases for the same kind of property 15-year bands have yielded poor results.

The band analysis seems to yield fairly consistent results for similar property in different places. For example, for cast-iron gas mains I obtained 98.9 years for Rochester, 85.8 years for Syracuse, 90.2 years in Long Island and 88.5 years in Brooklyn.

In smoothing the retirement ratios, I use a series of the form $Y=A+Bx+Cx^2+Dx^3+ \ldots$ where "x" represents the age in years

and "Y" the retirement ratios. I use only as many terms as are needed to obtain a good fit. It does not seem worth while to go beyond the third degree. Often observed ratios for the oldest plant are based upon scant data, and they are likely to be erratic. In general, I use the data up to a point at or near a marked deviation from a previously established trend. Carrying the calculation of the retirement ratio and the life table values to four decimal places is ordinarily enough to determine average service life to the nearest tenth of a year. But in many cases this will seem to be an over-refinement, because often the data are incomplete or inaccurate. The result should be regarded as an estimate, but in my opinion it is the best estimate that can be made.

There seems to be a tendency on the part of many in the profession to consider that physical decay is a function of age, but that inadequacy, obsolescence, and requirements of public authority are not. It is often pointed out that in electrical utilities over 75% of

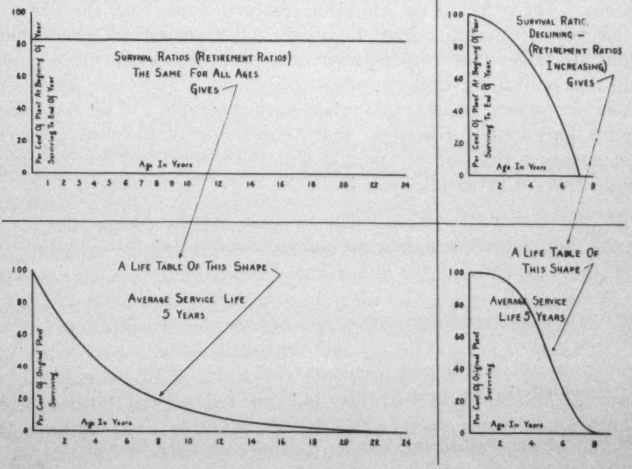

Survival Ratios (Retirement Ratios) The Same For All Ages Gives
Survival Ratio Declining — (Retirement Ratios Increasing) Gives
A Life Table Of This Shape
Average Service Life 5 Years
A Life Table Of This Shape
Average Service Life 5 Years
Age In Years
Per Cent Of Original Plant Surviving

FIG. 3.

retirements are for other than physical reasons and that, therefore, age as a factor in retirements can and should be disregarded. On the whole, this position seems to be untenable. While it is true that a new invention may come overnight, its effect in causing the retirement of existing property and particularly of long lived property is likely to be spread over many years because of the desirability of getting all that can be economically obtained out of our investments. The distribution of direct current in New York City is a case in point. Inadequacy causes piece-meal retirements more often than wholesale retirements.

The proof of the pudding lies in the eating. Construction of life tables of physical property in my office gives continually increasing support to the thesis that likelihood of retirement is a function of age. If this were not so, the values of the coefficients B, C, D, etc. in the equation for the retirement ratios would be zero, and the graph of the retirement ratios would be a horizontal straight line. This would mean that retirements were a matter of chance and were unrelated to age. The graph of the life table resulting would have the shape of a compound discount curve (Figure 3). But among the several hundred life tables that I have constructed from actual data from public utilities, only a few even approach such a shape, and these are exceptions for which ready explanations are available. The conclusion seems inescapable, therefore, that retirements of physical property are largely a function of age and that the estimate of service life is susceptible of actuarial analysis.

PROCEEDINGS

Sixty-First Annual Convention

Boston, Mass.

September 15 and 16, 1942

The following is a synopsis of those parts of the proceedings of the Sixty-first Annual Convention that appear to be of value for the record.

The Sixty-first Annual Convention of the New England Water Works Association was held at the Hotel Statler, Boston, Mass., on September 15 and 16, 1942.

Tuesday, September 15

Morning Session

The Convention was called to order at 10:30 a.m. by President Francis H. Kingsbury.

Administrative and Technical Reports

Copies of annual and final reports will be printed in the December 1942 Journal

The Annual Reports of the Secretary, Treasurer, Editor, and Finance Committee were presented, accepted, and ordered placed on file.

Upon motion of George A. Sampson, duly seconded, it was voted to adopt the Standard Specifications for Elevated Steel Water Tanks, Standpipes, and Reservoirs as included in the December, 1941, issue of the Journal.

The Annual Report of the Committee on Membership was read, accepted, and ordered placed on file.

A Report of the Committee on Emergency Water Service Schools was read by Joseph C. Knox and ordered referred to the Executive Committee.

Richard H. Ellis, as Chairman of the Committee on Meter Specifications recommended that copies of the Specifications prepared by a

joint committee of the American and New England Water Works Associations be bound into the JOURNAL in order to bring them to the attention of the members of the Association.

A Progress Report of the Committee on Rainfall and Yield of Drainage Areas was read by Ralph M. Soule.

The Annual Reports of the Committee on the Library and the Committee on Reciprocal Relations with the Institution of Water Engineers were read by E. Sherman Chase. A motion to instruct the Executive Committee to consider the advisability of establishing a committee on post-war activities as related to water works was carried.

The Annual Report of the Legislative Committee was read by Theodore L. Bristol, accepted, and ordered placed on file.

A Report of the Committee on Water Works Coöperation in Defense was read by Harry U. Fuller, accepted and ordered placed on file.

Joseph A. McCarthy read the Final Report of the Committee on the Revision of the U. S. Public Health Service Standards of Water Quality.

The Annual Report of the Committee on Committees was read by David C. Wiggin.

Secretary Gifford announced the election of the following to membership.

Members: Glen S. Weeks, Engineer and Superintendent of Public Works, Melrose, Mass.; Samuel O. Swartz, Bacteriologist, Metropolitan Water Works, Boston, Mass.; Guy E. Griffin, Captain, Quartermaster Corps & Corps of Engineers, Boston, Mass.; Richard H. Royce, Superintendent of Water Works, Rutland, Vt.; Elmer P. Tribou, Water Commissioner, Onset, Mass.; Harry L. Kinsel, Metcalf & Eddy, Consulting Engineers, Boston, Mass.; Simon P. Carman, Engineer in Charge, Bureau of Water, Binghamton, New York.

Corporate Members: Birmingham Water Company, Derby, Conn.; Board of Water Commissioners, Milton, Mass.

The PRESIDENT announced the following losses by death: James Bedell, Windsor, Vt.; J. S. Dunwoody, Erie, Pa.; William Flannery, New York, N. Y.; Leon A. Goodale, Worcester, Mass.; George H. Hazlehurst, Montgomery, Ala.; Samuel E. Killam, Boston, Mass.; George F. Merrill, Ware, Mass.; Alexander H. O'Brien, Holyoke,

Mass.; George H. Palmer, Hyannis, Mass.; Abel Reynolds, Providence, R. I.; Donald Sorelle, Acushnet, Mass.; and A. N. Talbot, Urbana, Ill.

Closing of Polls and Appointment of Tellers

The President declared the polls closed and appointed Roger G. Oakman, Ralph M. Soule and George G. Bean as tellers to count the ballots.

Luncheon Session

Award of the Dexter Brackett Memorial Medal

George A. Sampson. Mr. Baylis, Chairman of the Committee on the Award of the Dexter Bracket Memorial Medal, and twice a recipient of the medal, was unable to be here today, and has asked me to make the award. The medal was established in 1916 to commemorate the services of Dexter Brackett, beloved President of this Association in the years 1889 and 1890. It was made possible by contributions from members and is given each year for the paper, written by a member of the Association and published in the Journal of the previous year, which is judged the most meritorious based on its general applicability to water works problems. This is the twenty-sixth award.

I wish to point out to the members that one of the advantages of being on this Committee is that you have to read all of the papers published during the year, which aggregate over five hundred pages of text, written by forty or fifty authors. It is then that you begin to realize how much valuable information is contained in the Journal, and what a grand return a member of this Association receives for his dues.

Your Committee consisted of John R. Baylis, Roger W. Esty, and the speaker. We read carefully all of the papers in the 1941 Journal and then proceeded to ballot, each member submitting a list of papers arranged in the order of his preference. It is worthy to note that all three of us, one a chemist, another a superintendent, and the third an engineer, were in agreement on the first choice. As usual, there were other excellent papers published during the year, but the one which we judged most worthy for the award appeared in the June,

1941, issue, entitled "Hydraulic Investigation of Water Distribution Systems in Field and Office," by Gordon M. Fair, Professor of Sanitary Engineering, Harvard Graduate School of Engineering, a member of many technical societies and associations, a prolific writer of technical articles, the author of well known textbooks, a distinguished teacher, editor of the NEW ENGLAND WATER WORKS ASSOCIATION JOURNAL, and lately on a federal commission which is doing important work in South America.

Professor Fair, it gives me great pleasure on behalf of the New England Water Works Association to present you with this Dexter Brackett Memorial Medal.

GORDON M. FAIR. Mr. Sampson, Mr. President, ladies and gentlemen: The award of the Dexter Brackett Memorial Medal has long symbolized to me that which its founders, I believe, intended the ceremony to be: A tribute to a wise president of this Association, to an engineer self-taught yet outstanding in his profession, and to a New England gentleman of the old school, pleasant, courteous and kindly, beloved of those who worked with him and knew him.

I am proud that my paper on water distribution systems has been thought sufficiently worthy by your Committee to make me one of the principals in today's ceremony. I did not have the good fortune of knowing Mr. Brackett, but I have learnt from the memoir of his life, written for this Association by Frederick P. Stearns, Alfred Flinn and Allen Hazen, and from some of Mr. Bracketts papers, that one of his principal interests was the proper design and economic operation of water distribution systems. May I express the hope that my own contribution to this subject would have received the approbation of Mr. Brackett as well as of your Committee. I thank you.

Afternoon Session

Colonel Henry C. Hall, Director, War Department Civilian Protection School, Amherst College, Amherst, Mass., gave an address.

Arthur E. Gorman, Chief, Water Supply Section, Power Branch, War Production Board, Washington, D. C., read a paper, "Water—A Critical War Material." Paul B. Valle, assistant to Mr. Gorman, led the discussion, which was participated in by Roger W. Esty, Harry

U. Fuller, Harold W. Griswold, Linn H. Enslow, Henry T. Gidley, Donald C. Calderwood and William W. Brush.

There followed a Symposium on Priority Ratings and Water Works Materials, with R. K. Blanchard of Neptune Meter Company in the chair. The following subjects were discussed: Meters, by Mr. Blanchard; Storage Tanks, by J. A. Morley of Pittsburgh-Des Moines Steel Company; Hydrants, by Dennis F. O'Brien of A. P. Smith Manufacturing Company; Service Line Materials and Fittings, by Adolph Mueller and Mont E. Henderson of Mueller Company; Chemical and Feeding Equipment, by F. C. Clement of Wallace & Tiernan Company; Asbestos Cement Pipe, by C. T. Dearborn of Johns-Mansville Sales Corporation; Cast Iron Pipe, by H. Lloyd Nelson of U. S. Pipe & Foundry Company; Steel Pipe by E. H. Thwaits of American Iron & Steel Institute.

Wednesday, September 16, 1942

Morning Session

The general subject for discussion was "Wartime Problems of the Water Superintendent." Harold L. Brigham, Superintendent, Water and Sewage Commission, Marlborough, Mass., in the chair.

A paper, "Guarding Public Water Supplies," was read by Colonel Lewis E. Moore, U. S. Army, Headquarters First Service Command, Boston, Mass. This was discussed by W. W. Brush, E. Sherman Chase, and George G. Bean.

A lecture illustrated by stereopticon views was given by George R. R. Wahl, Engineer, Transite Pipe Department, Johns-Mansville Co., New York, N. Y.

A paper, "Wartime Problems in the Portland Water District," was read by Fred J. Reny, Treasurer and General Manager, Portland Water District, Portland, Maine.

A general discussion of "Labor Problems and Rate Problems Due to War Conditions" was participated in by Roger W. Esty, Henry T. Gidley, D. William Harford, and W. J. C. Marshall.

Report of Tellers of Election

Total number of ballots cast	239
Ballots counted	239

For President: Harold L. Brigham	237
For Vice-President: Karl R. Kennison	235
For Director: Donald C. Calderwood	235
For Treasurer: Frank J. Gifford	234

(*signed*) ROGER G. OAKMAN
GEORGE BEAN
RALPH M. SOULE

PRESIDENTIAL ADDRESS

By Francis H. Kingsbury, Retiring President

I appreciate the honor of having been President of your Association but I could not have carried out this work without the splendid coöperation of the various committees and also of the Water and Sewage Works Manufacturers Association. I am particularly grateful to your Technical Program Committee and to its Chairman, Joseph C. Knox.

These are troublesome times. The World since its nebulous beginning has revolved from west to east but our enemies would reverse it. In the year now closing our Association has met many problems. There is still much work to do!

I thank you again for your coöperation and extend a wish for an active new year.

The President then introduced the President-Elect, Harold L. Brigham.

MR. BRIGHAM. Mr. President and gentlemen of the New England Water Works Association: I am certainly deeply appreciative of the honor that has been conferred upon me by election to be your president for the coming year. Just fifty years ago my predecessor as water works superintendent of my home town became president of this Association. I do not believe that there are many with us today, with the exception possibly of Frank Northrop, who were present at that time. He did, however, have a very successful administration, and those were critical times in the history of this Association. It was then in its infancy. I hope that I may also be as successful as he was, for these are also critical times, not only in the life of our industry but

in the very life of this Nation itself. From what we have heard from the speakers who have been heard so far and from the officials in Washington, there are hard times ahead for the water works fraternity. To quote Mr. Gorman and Mr. Valle: apparently for some little time to come the water works will have to live off their own fat, so to speak. We are going to be called upon to do seemingly impossible things. However, I do have faith in the water works fraternity to overcome these difficulties if each and every one will do his full share. You are going to be called upon to do your share. In closing I want to say that I believe that we can, we will, and we must. I thank you.

Afternoon Session

President Kingsbury in the chair.

A paper, "Training and Organization of Technical Consultants to Deal with Chemical and Bacterial Contamination," was read by Leon A. Bradley, Ph.D., Head of Bacteriology Department, Massachusetts State College, Amherst, Mass.

A paper, "Chemical Contamination of Public Water Supplies," was read by Lazarus Rubin, Senior Chemist, Massachusetts Department of Public Health, Boston. Warren J. Scott and E. Sherman Chase took part in the discussion.

A paper, "Bacterial Course at the Decontamination School," was read by Joseph A. McCarthy, Chief of Laboratory, Lawrence Experiment Station, Lawrence, Mass. The paper was discussed by E. Sherman Chase.

(Adjourned)

INDEX OF ADVERTISERS

	Page
Atlas Mineral Products Co.	xvi
Bailey, Howard E.	ii
Barbour, Frank A.	ii
Barrows, H. K.	ii
Bingham & Taylor	iv
Builders-Providence, Inc. Division of Builders Iron Foundry	xiii
Cast Iron Pipe Research Assn.	xxxi
Cement Lined Pipe Co.	viii
Crosby, Irving B.	ii
Donaldson Iron Co.	xvii
Dresser Mfg. Co.	Following front cover
Eddy Valve Co.	xv
Edson Corp., The	xxii
Ellsworth, Samuel M.	ii
Eureka Pipe Co., Inc.	viii
Fairbanks-Morse Co.	xii
Fay, Spofford & Thorndike	ii
Ford Meter Box Co.	xvii
Hays Mfg. Co.	xviii
Hersey Mfg. Co.	v
Hydraulic Development Corp.	x
Jackson, Henry D.	iii
Johns-Manville	xi
Kennedy Valve Mfg. Co.	xiv
Knowles, Morris, Inc.	ii
Leadite Co.	Back cover
Lock Joint Pipe Co.	Facing front cover
Ludlow Valve Mfg. Co. Inc., The	ix
Metcalf & Eddy	ii
Morris Machine Works	xix
National-Boston Lead Co.	xvi
National Gunite Contracting Co.	iii
National Water Main Cleaning Co.	viii
Neptune Meter Co.	vii
Newsom & Aldrich	ii
Pierce-Perry Co.	viii
Pirnie, Malcolm	iii
Pitometer Co.	iii
Pittsburgh Equitable Meter Co.	Following front cover
Potts, Clyde	ii
Red Hed Mfg. Co.	xxv
Rensselaer Valve Co.	xxiii
Reppucci, C. & Sons, Inc.	iii
Ross Valve Mfg. Co.	xxiv
Smith, The A. P., Mfg. Co.	xvii
Turbine Equipment Co.	xx
U. S. Pipe and Foundry Co.	Facing back cover
Wailes Dove-Hermiston Corp.	xxiii
Wallace & Tiernan	xxi
Warren Foundry and Pipe Corp.	xxii
Weston & Sampson	iii
Whitman & Howard	iii
Wood, R. D., Co.	xxvi
Worthington Pump and Machinery Corp.	vi

(Classified index on page xxvii)

ENGINEERS

HOWARD E. BAILEY

Consulting Sanitary Engineer

Water Works — Water Purification
Sewerage — Sewage Treatment
Industrial Wastes Disposal

177 State St., Boston, Mass.

FRANK A. BARBOUR

Consulting Engineer

Water Supply, Water Purification, Sewer and Sewage Disposal, Valuations

Tremont Building, Boston, Mass.

H. K. BARROWS

M. Am. Soc. C. E.

Consulting Hydraulic Engineer

Water Power, Water Supply, Sewerage, Drainage, Investigations, Reports, Valuations, Designs, Supervision of Construction

BOSTON, MASS. — 6 BEACON ST.

IRVING B. CROSBY

Consulting Engineering Geologist

Investigations of Dam and Reservoir Sites and Groundwater Supplies

6 BEACON ST. — BOSTON, MASS.

Reeves Newsom — E. H. Aldrich

NEWSOM & ALDRICH

Engineer-Consultants

Water Supply, Purification and Distribution
Sewerage and Sewage Disposal
Valuations and Reports

500 Fifth Ave., New York — Williamsburg, Va. Harrisburg, Pa.

Samuel M. Ellsworth

M. Am. Soc. C. E.

Consulting Engineer

Water Supply and Sewerage

Investigations, Reports and Designs, Supervision of Construction and Operation

6 Beacon Street, Boston

FAY, SPOFFORD & THORNDIKE

ENGINEERS

Frederic H. Fay — Charles M. Spofford
John Ayer — Bion A. Bowman
Carroll A. Farwell — Ralph W. Horne

Water Supply—Sewerage—Drainage
Structural and Foundation Problems
Investigations Reports Designs Valuations
Engineering Supervision

11 BEACON STREET — BOSTON

MORRIS KNOWLES, INC.

Engineers

Water Supply and Purification, Sewerage and Sewage Disposal, Industrial Wastes, Valuations, Laboratory, City Planning.

1312 PARK BUILDING
PITTSBURGH, PA.

METCALF & EDDY

ENGINEERS

Water, Sewage, Drainage, Garbage and Industrial Wastes Problems

Laboratories — Valuations

BOSTON, MASS.
Statler Building

CLYDE POTTS

M. Am. Soc. C. E.

Consulting Sanitary Engineer

30 Church Street - - New York

Sewerage and Sewage Disposal
Water Works and Water Supply
Reports, Plans and Estimates

ENGINEERS

MALCOLM PIRNIE
ENGINEER
Water Supply, Treatment, Sewerage
Reports, Plans, Estimates,
Supervision and Operation,
Valuation and Rates.
25 West 43rd Street, New York, N. Y.

WESTON & SAMPSON
Consulting Engineers
Robert Spurr Weston George A. Sampson
Water Supply and Sewerage
Chemical and Bacteriological
Laboratory
14 BEACON ST. BOSTON, MASS.

THE PITOMETER COMPANY
ENGINEERS
Water Waste Surveys
Trunk Main Surveys
Water Distribution Studies
Penstock Gaugings
50 Church Street New York City

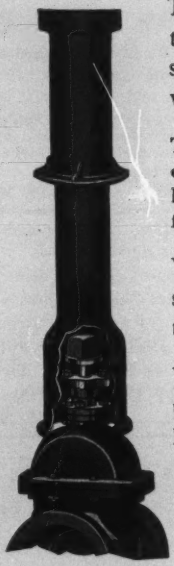
WHITMAN & HOWARD
HARRY W. CLARK, Associate
Civil Engineers
(Est. 1869. Inc. 1924.)
Investigations, Designs, Estimates, Reports and Supervision, Valuations, etc., in all Water Works and Sewerage Problems
89 BROAD ST. BOSTON, MASS.

RESERVOIRS and TANKS
LINED and RESTORED
with
GUNITE
NATIONAL GUNITE CONTRACTING COMPANY
Engineers and Contractors
82 W. Dedham St. BOSTON

For Valves, Hydrants and
Centrifugal Pumps
Lasts longer, operates easier,
reduces wear
Costs far less in the long run
ACE O PAX #4 and #90
No Rubber or Binder *No Rot*
HENRY D. JACKSON
29 Noyes St. Concord, N. H.

C. REPPUCCI & SONS, INC.
GENERAL CONTRACTORS
Ground Water Supply
Gravel Packed Wells Driven Wells
Water Works Reservoirs
Drainage and Sewerage Works
10 Garden Court Street (Tel. Lafayette 7330) Boston, Mass.

BINGHAM & TAYLOR'S Sliding Type Service and Valve Boxes are meeting with the approval of many New England Waterworks officials.

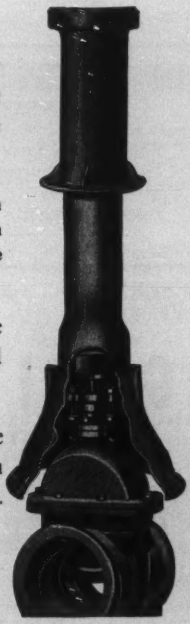


The cuts shown are our two and three piece sliding type adjustable valve boxes.

The flange on the bottom of the top section can be located any distance from the top.

We carry a complete stock on hand at all times.

Wire, phone or write us when you are in a hurry for a shipment.

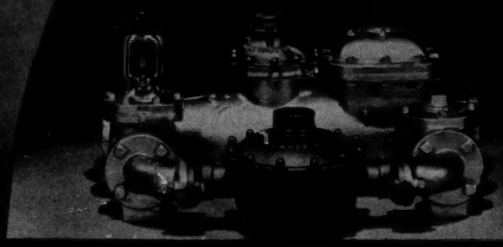


Bingham and Taylor Corporation

MANUFACTURERS

575-601 Howard Street - - Buffalo, N. Y.

HERSEY



HERSEY DETECTOR METERS

are safeguarding the water supply of fire services so necessary for the protection of the country's large industries. This, however, is not a new or sudden war measure but does take on added importance at this time when water supplies are strained to their utmost.

For more than thirty years Hersey Detector Meters have had general water works acceptance and the approval of the National Board of Underwriters.

HERSEY MANUFACTURING COMPANY
SOUTH BOSTON, MASS.

BRANCH OFFICES: NEW YORK — PORTLAND, ORE. — PHILADELPHIA — ATLANTA — DALLAS
CHICAGO — SAN FRANCISCO — LOS ANGELES

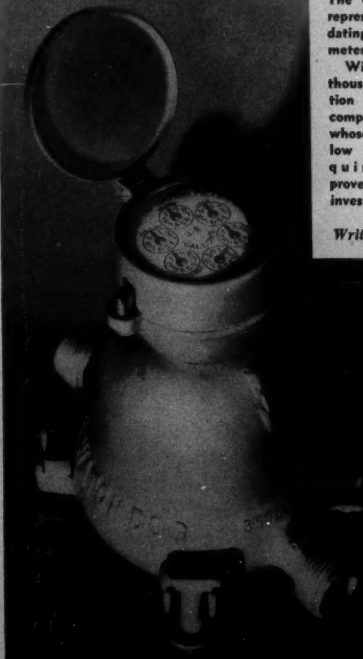
WATCH DOG WATER METERS

. . . built to give LASTING SATISFACTION

The Worthington-Gamon Meters of today represent an experience of 85 years . . . dating back to the invention of the piston meter, in 1855, by Henry R. Worthington.

With 3,650,000 meters now serving thousands of communities, this organization offers to municipalities and water companies a product whose accuracy and low maintenance requirements have proved it to be a sound investment.

Write for literature.



WORTHINGTON-GAMON METER COMPANY
General Offices: HARRISON, NEW JERSEY

WORTHINGTON-GAMON

WG1-2A

How

Your Water Works Can Help

To Win the War

YOU, in charge of Water Works, see men going off to the Army and Navy. You see them streaming to the plants engaged in War Work. And maybe you're wondering what YOU can do to help in YOUR job . . . *"what's the Water Works got to do with war production, anyway?"*

More than you realize, perhaps! For you can help by preventing waste of materials vitally needed for war production. One method is a program of modern meter conservation which will result in reducing your pumpage . . . and save not only water, but chemicals to treat it and fuel to pump it.

If your town and hundreds of other towns can reduce your pumpage (as did Hickory, N. C.) even 2.2% — and many can do FAR more — you will contribute much to the job ahead of all of us.

What is a Meter Conservation Program? It is a plan of periodic meter testing and repairing — one example of which is quoted here. No matter *what* water meters you use, your nearest Trident Meter representative will be glad to advise you about such a program, without obligation on your part. Write for Bulletin 597a. Start your Water Works helping to win the war — today!

★ ★ ★ ★ **HICKORY, N. C., HELPS** ★ ★ ★ ★ ★

and gets increased revenue to boot!

When their meter testing and repair program started, Hickory, N. C., discovered many meters were "dead", (not registering). Within 10 months they saw that definite economies had been effected. The replacement of a 2" Compound meter with one newly repaired and tested, for example, resulted in a 16.7% increase in revenue in that period.

Small (domestic) meters, averaging 14 years old (without repairs), cost a fraction over $2.00 apiece for repairs needed to bring them to 90% (or greater accuracy) at the rate of ¼ g.p.m. Result—pumping—down 2.2%; revenue—up $2,539.99, more than paying for the cost of the program.

NEPTUNE METER COMPANY • 50 West 50th Street • NEW YORK CITY

Branch Offices in CHICAGO, SAN FRANCISCO, LOS ANGELES, PORTLAND, ORE., DENVER, DALLAS, KANSAS CITY, LOUISVILLE, ATLANTA, BOSTON.

Neptune Meters, Ltd., Long Branch, Ontario, Canada.

2 for 1

Play Safe

in your selection of Service Pipe

Eliminate the danger of metal poisoning and at the same time eliminate corrosion.

Specify EUREKA Cement Lined Pipe

IMMEDIATE DELIVERY TO WATER WORKS

EUREKA PIPE COMPANY, Inc.

MANUFACTURERS OF

Centrifugal Cement Lined Pipe — Lead and Tin Fittings

591-593 WASHINGTON ST. TEL. 3-9550 LYNN, MASS.

Health and Protection First

Water delivered through dirty pipes may be a MENACE.

Incrusted water pipes mean inefficiency and loss of Fire Protection.

We Guarantee the Results of Our Method of Cleaning.

WRITE US.

National Water Main Cleaning Co.

30 Church Street New York City

Cement Lined Service Pipe

Cement lined pipe has eliminated corrosion and metal contamination for 60 years

Write for Literature

Cement Lined Pipe Co.

Lynn, Mass.

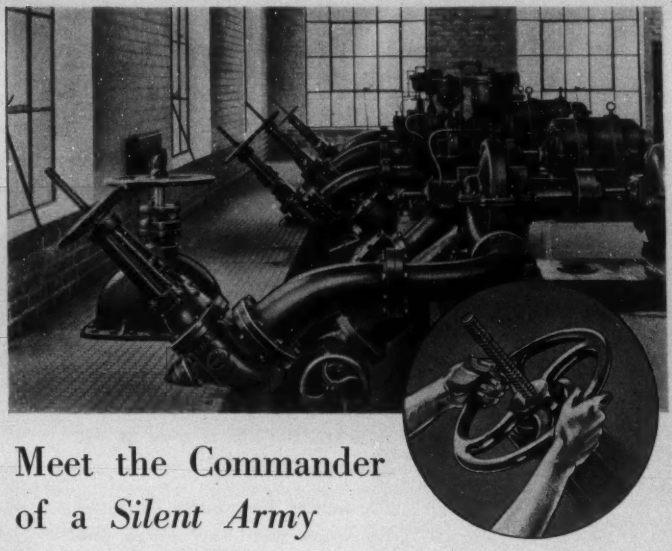
PIERCE - PERRY CO.

Wholesalers of

Water Works Brass Goods.
Byers Wrought Iron Pipe.
Youngstown Steel Pipe.
Valve and Service Boxes.

236 Congress St., Boston, Mass.

Telephone, Hancock 7817-7818



Meet the Commander of a *Silent Army*

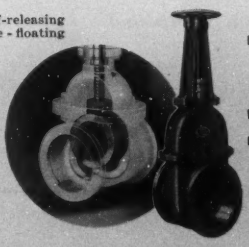
These hands control the actions of a mute army of soldiers. They wear no uniforms, require no pay. Yet they are always at their stations, ready for instant action — and upon them may depend the fate of the community!

These silent soldiers comprise the network of Ludlow Valves at the pump house and throughout the water works system — ready to respond quickly and efficiently in routine or emergency.

Ludlow Valves employ the famous double-disc, parallel seat principle, developed and perfected by Ludlow over a period of three-quarters of a century. This system assures easy operation and positive closure — even after years in the open position.

THE LUDLOW VALVE MFG. CO., INC.
TROY, NEW YORK

Construction Features: Self-releasing 30° angle wedges and free-floating gates, self-adjusting to seats, afford smooth, trouble-free performance, long service. Rings are cleaned throughout stroke action. Gates are wedge-locked directly opposite ports and completely unwedged before raising. Ample tolerances provide easy action. Simple construction permits easy replacement of parts.



LUDLOW VALVES

SINCE 1866

TIGHT JOINTS

REGARDLESS OF PIPE SIZE OR SOIL CONDITION

UNDER all conditions of service cast iron water mains can be laid with assurance of permanently "bottle-tight" joints if HYDRO-TITE is used as the jointing compound.

No matter how large or small the pipe nor how tough the going may be, HYDRO-TITE will prove the easiest and most economical to use.

HYDRO-TITE has a record of more than a quarter century without a failure anywhere.

A Symbol of Quality

A Dependable Self-Caulking Joint Compound

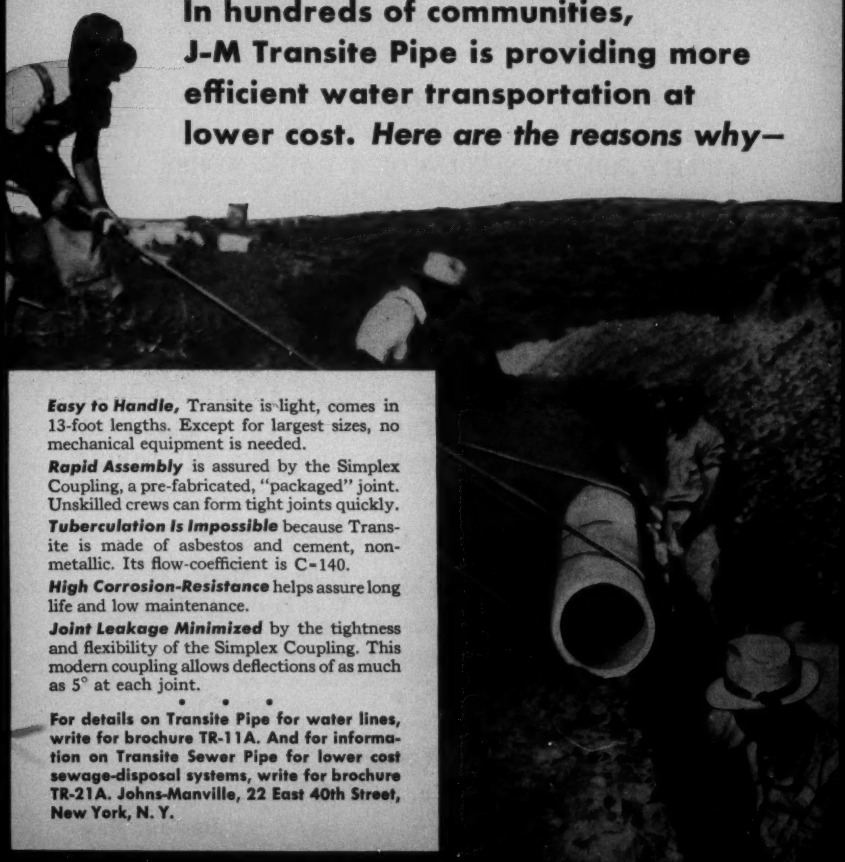
HYDRO-TITE

HYDRAULIC DEVELOPMENT CORPORATION

Main Sales Office: 50 Church Street, New York, N. Y.
General Offices and Works: West Medford Station, Boston, Mass.

ALL OVER THE COUNTRY!

In hundreds of communities, J-M Transite Pipe is providing more efficient water transportation at lower cost. *Here are the reasons why—*



Easy to Handle, Transite is light, comes in 13-foot lengths. Except for largest sizes, no mechanical equipment is needed.

Rapid Assembly is assured by the Simplex Coupling, a pre-fabricated, "packaged" joint. Unskilled crews can form tight joints quickly.

Tuberculation Is Impossible because Transite is made of asbestos and cement, non-metallic. Its flow-coefficient is C=140.

High Corrosion-Resistance helps assure long life and low maintenance.

Joint Leakage Minimized by the tightness and flexibility of the Simplex Coupling. This modern coupling allows deflections of as much as 5° at each joint.

• • •

For details on Transite Pipe for water lines, write for brochure TR-11A. And for information on Transite Sewer Pipe for lower cost sewage-disposal systems, write for brochure TR-21A. Johns-Manville, 22 East 40th Street, New York, N. Y.

JM

Johns-Manville TRANSITE PIPE

An asbestos product for more efficient, economical water & sewer lines

"EVERYTHING-BY-ONE-MANUFACTURER"

HAS ALWAYS HELD APPEAL FOR ENGINEERS WHO WANTED TO PLACE ON ONE FIRM UNDIVIDED RESPONSIBILITY FOR THE SUCCESS OF A WATER WORKS' EQUIPMENT.

IN THESE DAYS, THAT UNIFICATION DOES EVEN MORE. IT REDUCES THE TERRIFIC TASK OF COORDINATING SHIPMENT FROM DIFFERENT FIRMS, EACH OF WHICH OPERATES ON WIDELY VARIED WARTIME SCHEDULES.

NEW CONCENTRATIONS OF INDUSTRY AND ITS WORKERS IN NEW ENGLAND RAISE PRESSING WATER WORKS PROBLEMS. LET FAIRBANKS, MORSE SHOULDER THE LARGER PART OF THEM.

New installations by Fairbanks, Morse at

Windsor, Vermont
Springfield, Vermont
Hill, N. H.
Methuen, Mass.
West Boylston, Mass.
Cumberland, R. I.

•

Write to

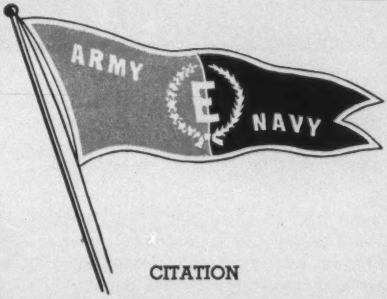
FAIRBANKS, MORSE & CO.

178 Atlantic Avenue **Boston, Mass.**

TO THE MEN AND WOMEN OF

BUILDERS IRON FOUNDRY

THE ARMY-NAVY PRODUCTION AWARD



CITATION

..."a Nation's tribute to the spirit of patriotism and high achievement in production of war equipment, exceeding all expectations"

BUILDERS IRON FOUNDRY

(BUILDERS-PROVIDENCE, INC.)

PROVIDENCE . . . RHODE ISLAND

★ ★ ★

Contributors to the Nation's Peace and War Efforts since 1820

BUILDERS

WATER AND SEWAGE WORKS

Equipment

..... How much do YOU pay for repairs to broken hydrants?

$50

$10

When ordinary designs of fire hydrants are broken by an automobile out of control or a heavy truck, the entire standpipe must be replaced, requiring a lengthy and costly repair job.

On the other hand, the Kennedy SAFETOP, while fully as strong and as resistant to ordinary impacts as a one-piece hydrant, limits breakage from smashing impacts to inexpensive, easily replaceable parts.

No water is lost; and the entire repair job can be done by one man, within half an hour, without excavating, and at a total cost of less than $10.00 for repair parts and labor.

Many thousands of Kennedy SAFETOPS are in service; and the water department superintendents responsible for them are enthusiastic about their dependability, easy operation, and low maintenance cost.

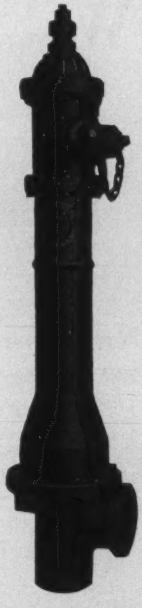
The Kennedy Valve Mfg. Co., Elmira, N. Y.

KENNEDY SAFETOP FIRE HYDRANT

REG. U.S. PAT. OFF.

EDDY

Valves and Hydrants



Distinctive Features of the EDDY Valves

ONLY three parts are moved by the Stem—the ball and the two gates. Each gate is hung from one of the trunnions on the ball. A convex surface at the base of each trunnion fits a concave surface on the back of the gate. This allows the gates to adjust themselves properly to their seats. . . . The gates, being free to revolve on the trunnions, do not always seat in the same position. Gates are center bearing and adjustable. They are forced to their seats with equal pressure at all points. There are two hooks on the ball on sizes 4-inch and larger, which loosely engage with the gates.

Distinctive Features of Our New Swivel Top Hydrants

THIS new hydrant has all the advantages of the popular EDDY fire hydrant, plus several additional features. . . . Nozzles are in a short flanged section of the standpipe, which may be unbolted and turned to different positions. . . . Should the standpipe be broken, only the casting below the swivel head need be replaced. . . . To raise the hydrant to conform to a new grading, simply insert a flanged extension piece below the swivelhead. No digging. To add a steamer nozzle at any time, it is only necessary to replace the swivel head with one having a steamer nozzle.

Besides valves and hydrants to meet the most exacting demands of waterworks service, the complete EDDY Line includes: valves for sewage disposal works; valves for steam, gas and oil; check valves, foot valves, plug valves, shear gates, indicator posts, etc. EDDY valves are made in three classes: Iron Body Bronze Mounted, All Bronze, and All Iron Valves.

Eddy Valve Co.

WATERFORD NEW YORK

WHEN LAYING WATER MAINS TODAY . . .

Remember that joints caulked with lead are soft and flexible . . . take up normal pipe movement without leakage . . . stay tighter longer.

Remember, too, that there is no current shortage of lead . . . no ruling which prohibits the use of lead for caulking purposes.

We furnish lead either in ingot form for cast joints or as lead wool for cold caulking. Both carry the Lead Industries Association Seal of Approval—a guarantee of their purity.

National-Boston Lead Company

900 ALBANY STREET **BOSTON, MASS.**

INGOT LEAD — LEAD WOOL — LEAD PIPE
SOLDER — WHITE LEAD — RED LEAD

"SOMETHING NEW has been added"

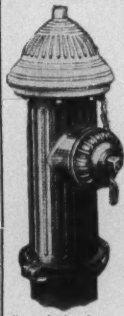
THIOKOL (synthetic rubber) added to the sulphur base of *Tegul*-MINERALEAD, reduces initial leakage to far below that usually experienced with jointing compounds, and also hastens the sealing of such leakage. ■ This speeds the laying of bell and spigot pipe lines, and permits immediate backfilling and clearing up of premises. ■ *Tegul*-MINERALEAD makes sturdy, permanently tight joints with far above average resistance to thermal and mechanical shock.

Tegul-M, in 10 lb. ingots, impervious to moisture, easily handled and stored, is stocked at central points over the U. S. A. and in Hawaii. For technical literature, write The ATLAS MINERAL Products Company of Penna., Mertztown, Pennsylvania.

Tegul-MINERALEAD

for Jointing Bell & Spigot Main

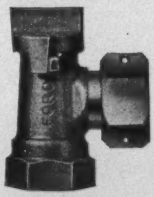
THE A. P. SMITH MFG. CO.,
East Orange, New Jersey



Manufacturers of high-grade specialties in connection with water and gas department work, consisting of—
Machines for inserting valves under pressure, and for making large right angle connections to mains under pressure, and for inserting house service connections under pressure.
Also makers of—
Pipe Cutting Machines, each size being adjustable for use on three different sizes of pipe.
High-grade water works supplies, such as Hydrants, Valves, Meters, Corporation Cocks, etc.
We also make a new type of hydrant which has a breakable joint at the ground line which when struck with an impediment will break at a specified point and only a coupling has to be used to repair the hydrant, which will be back in service in twenty (20) minutes.
"HYDRANT WITH BREAKABLE COUPLING"

SMITH
WATER WORKS SPECIALTIES & SUPPLIES
THE A.P.SMITH MFG.CO. *East Orange,N.J*

Ringstyle



The Ford RINGSTYLE Valve is an inverted key angle valve with meter coupling nut attached. For pit settings where meter is set on risers it makes a most convenient and satisfactory curb valve. Hundreds of thousands in service. Write for catalog and further information.

FORD METER BOX CO.,
WABASH, IND.

DONALDSON IRON CO.

MANUFACTURERS
. . . OF . . .

CAST IRON PIPE

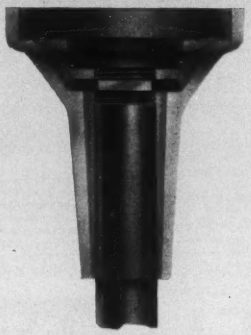
. . . AND . . .

Special Castings for Water and Gas
Also Flange Pipe and Fittings

EMMAUS, LEHIGH COUNTY, PA.

New York Office: E. A. NOONAN, 225 Broadway

New!



HAYS

SERVICE BOX SLEEVE

Always Visible . . . Always Accessible

A timely device for these critical days, insuring quick location and easy manipulation of curb box shut-offs in any emergency. Easy to install on either new or present service boxes. Keeps service box extensions at proper level. Keeps service box cover free from cement or other surrounding material, making removal quick and easy. No groping in the dark. No chipping of cement. No desperate smashing of box lids in a crisis. The Hays Service Box Sleeve is a boon to utilities service men, property owners, air raid wardens or other public officers.

Write for Hays booklet, which gives complete information on this timely item.

HAYS MANUFACTURING COMPANY, ERIE, PENNA.

COPPER • BRASS • LEAD • IRON

HAYS *Water Works* PRODUCTS

HAYS MFG. CO., ERIE, PA. • *Since 1869*

"90% Efficiency? Impossible!" but the MORRIS Pumps did it

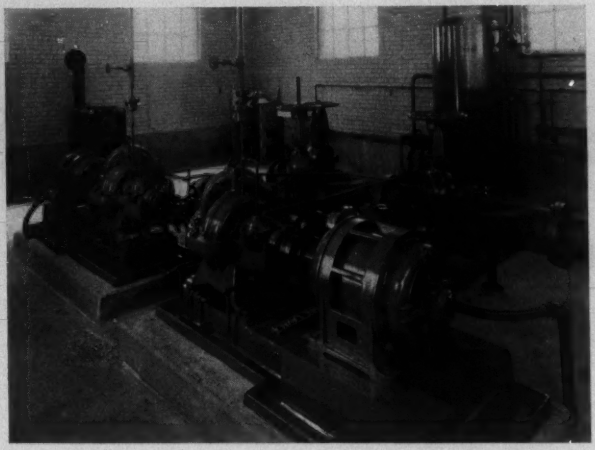
The customer's engineer was skeptical. But on acceptance test, these 48-inch MORRIS pumps actually exceeded the MORRIS guarantee . . . as usual. MORRIS recommendations . . . like MORRIS Pumps . . . are dependable, because the 78-year MORRIS experience has covered practically every operating condition on which a centrifugal pump can be used. You are SAFE when you come to MORRIS.

STARKWEATHER ENGINEERING CO. MORRIS ESTABLISHED 1864 NEWTON, MASSACHUSETTS

CENTRIFUGAL PUMPS

DE LAVAL

CENTRIFUGAL WATER WORKS PUMPS



Town of Maynard — White Pond Station

The pumping station shown above was designed by F. A. BARBOUR, Consulting Engineer and includes two automatically operated, motor driven DE LAVAL pumping units. Official acceptance test results were significantly higher than the guarantees.

If your requirements are increasing or new sources of supply necessitate additional pumps, we believe DE LAVAL equipment will be of interest.

TURBINE EQUIPMENT COMPANY OF NEW ENGLAND

80 Federal Street **Phone LIBerty 5993-5994** **Boston, Mass.**

New England Representatives for

DE LAVAL STEAM TURBINE COMPANY

TRENTON, NEW JERSEY

ON GUARD

SHOULD WAR EMERGENCIES STRIKE..
..YET ON THE GO IN THE MEANTIME

W & T *Chlorination* TRAILER

The W&T Chlorination Trailer is specifically fitted to cope with sudden war emergencies, yet its ready usefulness for daily needs keeps it on the go in any event. Foresighted communities that have purchased this unit are finding that it "pays its way" for sterilizing mains, for treating secondary reservoirs or temporary supplies, and for many other chlorination needs away from the plant... needs which may arise in peace or in war. The community is more fully protected in case of floods, droughts and other natural emergencies, as well as from wartime dangers.

Built to take hard service day after day, this W&T equipment can be kept busy without lowering its ability to meet a crisis if need be. And after the war, it will still justify itself with many years of useful peacetime performance. The unit is complete with tools, connecting cocks and hose, and provides self-powered solution feed of chlorine from two 150 lb. cylinders cradled within it. Chlorine can be applied over a wide range of application rates up to 300 lb. per day.

Wallace & Tiernan Representatives will be glad to give you complete details on the W&T Chlorination Trailer, on the new W&T Portable Chlorinator, and other units which fit into the over-all picture of wartime water protection, or write for Technical Bulletin.

136-S

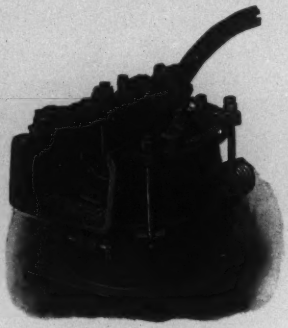
"The Only Safe Water is a Sterilised Water"

WALLACE & TIERNAN CO., Inc.

MANUFACTURERS OF CHLORINE AND AMMONIA CONTROL APPARATUS

NEWARK, NEW JERSEY • REPRESENTED IN PRINCIPAL CITIES

EDSON
PUMPS and ACCESSORIES



Hand Pumps – Power Pumps
Truck or Trailer Mounted
Edson Special Suction Hose
Red Seal Diaphragms
Edson Bronze Hydrant Pump
Strainers, Adapters, etc.

Distributors for
Pollard Pipe Line Equipment
Electric Pipe Thawers

Universal Pipe Locator
Universal Water Leak Detector

THE EDSON CORPORATION
49 D Street, Tel. SOUth Boston 3041 South Boston
New York: 142 Ashland Place, Brooklyn

Warren Foundry & Pipe Corp.
ALSO
Warren Pipe Co. of Mass., Inc.
SALES OFFICES
11 BROADWAY, NEW YORK
75 FEDERAL STREET, BOSTON, MASS.
Manufacturers of
CAST IRON PIPE
Flanged Pipe *Flexible Joint Pipe*
Bell and Spigot Pipe
Special Castings *Short Body B. & S. Specials*
Warren (WF) Spun Centrifugally Cast Iron Pipe

WORKS: PHILLIPSBURG, N. J. and EVERETT, MASS.
Large Stock Enables Us to Make Prompt Shipments

For an Extremely Smooth Pipe Interior
SPECIFY

SPUN **BITUMASTIC** LINING
REG. U.S. PAT. OFF.

This Will Assure You of
NO LOSS IN CAPACITY
NO TUBERCULATION OR INCRUSTATION
NO EFFECT ON WATER QUALITY

Recent Repeat Flow Test Shows High Williams Hazen Coefficient Unchanged After EIGHT YEARS

Wailes Dove-Hermiston Corporation

General Offices: Westfield, N. J.
New York District Office: 17 Battery Place, N. Y. C.

Buy RENSSELAER Products

- Gate Valves
- Check Valves
- Corey Hydrants
- Air Valves
- Cone Valves
- Grease Cases
- Tapping Valves, Sleeves and Crosses

Ask for Catalogue G

Rensselaer Valve Co. **Troy, N. Y.**

HERBERT B. CROWELL
Sales Manager, New England Branch

3 WASHINGTON SQUARE **HAVERHILL, MASSACHUSETTS**

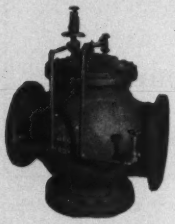
1879—ROSS— 1879

AUTOMATIC VALVES

Controls elevation of water in tanks, basins and reservoirs

ALTITUDE VALVE

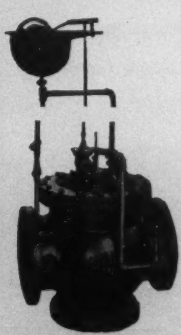
1. Single Acting
2. Double Acting



Maintains desired discharge pressure regardless of change in rate of flow

REDUCING VALVE

Regulates pressures in gravity and pump systems; between reservoirs and zones of different pressures, etc.



Maintains levels in tank, reservoir or basin

1. As direct acting

2. Pilot operated and with float traveling between two stops, for upper and lower limit of water elevation.

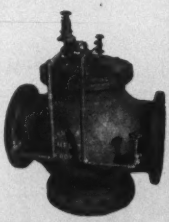
FLOAT VALVE

A self contained unit, with three or more automatic controls

COMBINATION VALVE

Combination automatic control both directions through the valve.

Maintains safe operating pressures for conduits, distribution and pump discharge



SURGE-RELIEF VALVE

Electric remote control—solenoid or motor can be furnished

REMOTE CONTROL VALVE

Adapted for use as primary or secondary control on any of the hydraulically controlled or operated valves.

ROSS VALVE MFG. CO., INC. Box 592 TROY, N. Y.

R
HED
D

WE HAVE IN STOCK

a limited amount of

RED HED BRASS GOODS

WHICH WE ARE PERMITTED TO SELL,

When Proper Priorities Are Furnished

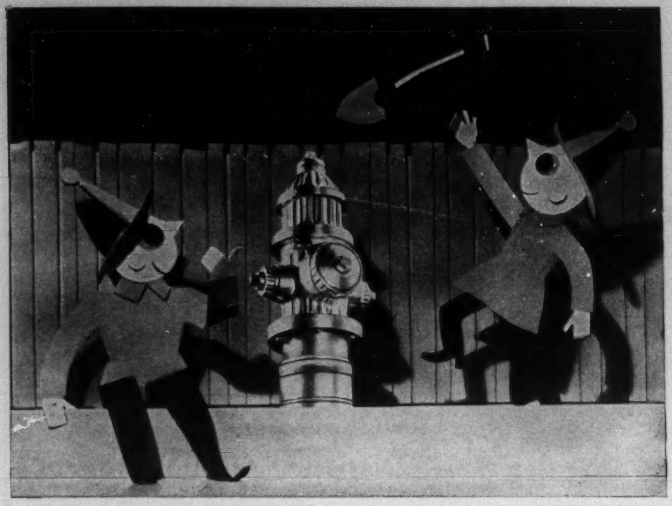
★

RED HED MFG. CO.

Manufacturers of

RED HED Brass Goods for Water Works

368 Congress Street Boston, Mass.



"GIVE YOUR SHOVEL TO THE SCRAP DRIVE"

WE NEVER DIG UP A MATHEWS

The community that has Mathews Hydrants is extra lucky in war time. Once-a-year oiling is the only service they need. Repairs are made with few parts, few men, and *no digging*. For the entire barrel, containing all working parts is as interchangeable as a spare tire. This takes care of traffic smashes, major repairs or overhauls, and modernization. And all parts except those actually broken can be used again.

No wonder Mathews Hydrants have been "tops" for over 70 years.

MATHEWS HYDRANTS

400 CHESTNUT STREET, PHILADELPHIA, PA.

ESTABLISHED IN 1803

Made by R.D.WOOD Company

MANUFACTURERS OF SAND SPUN PIPE (CENTRIFUGALLY CAST IN SAND MOLDS) AND R. D. WOOD GATE VALVES

CLASSIFIED DIRECTORY OF ADVERTISEMENTS

Page

AIR CONDITIONING EQUIPMENT.
Worthington Pump and Machinery Corp. vi

AIR COMPRESSORS.
Worthington Pump and Machinery Corp. vi

ASBESTOS CEMENT PIPE.
Johns-Manville xi

BRASS GOODS.
(See also Pipe, Brass.)
Cement Lined Pipe Co. viii
Hays Mfg. Co. xviii
Pierce-Perry Co. viii
Red Hed Mfg. Co. xxv
Smith Mfg. Co., The A. P. xvii

CALKING MACHINERY AND TOOLS.
Smith Mfg. Co., The A. P. xvii

CAST IRON PIPE. (See Pipe, Cast Iron.)

CEMENT LINED PIPE. (See Pipe, Cement Lined.)

CHEMICAL FEED APPARATUS.
Builders-Providence, Inc.
Division of Builders Iron Foundry xiii
Wallace and Tiernan Co., Inc. xxi

CHLORINATORS.
Builders-Providence, Inc.
Division of Builders Iron Foundry xiii
Wallace and Tiernan Co., Inc. xxi

CLAMPS, RIVER.
Dresser Mfg. Co. ..... Following front cover

CLEANING WATER MAINS.
National Water Main Cleaning Co. viii

COCKS, CURB AND CORPORATION.
Hays Mfg. Co. xviii
Pierce-Perry Co. viii
Red Hed Mfg. Co. xxv
Smith Mfg. Co., The A. P. xvii

CONCRETE PIPE. (See Pipe, Concrete.)

CONDENSERS.
Worthington Pump and Machinery Corp. vi

CONTRACTORS' EQUIPMENT.
Morris Machine Works xix
Worthington Pump and Machinery Corp. vi

CONSTRUCTION EQUIPMENT.
Edson Corp., The xxii

CONSTRUCTION AIR TOOLS.
Worthington Pump and Machinery Corp. vi

CONTRACTORS.
National Water Main Cleaning Co. viii
Reppucci, C. & Sons, Inc. iii

COUPLINGS, FLEXIBLE PIPE.
Dresser Mfg. Co. ..... Following front cover

CURB BOXES.
Bingham and Taylor iv
Hays Mfg. Co. xviii

DIAPHRAGMS, PUMP.
Edson Corp., The xxii

CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued)*

Page

ENGINEERS.
Bailey, Howard E. ... ii
Barbour, Frank A. ... ii
Barrows, H. K. ... ii
Crosby, Irving B. ... ii
Ellsworth, Samuel M. ... ii
Fay, Spofford & Thorndike ... ii
Knowles, Morris, Inc. ... ii
Metcalf & Eddy ... ii
Newsom & Aldrich ... ii
Pirnie, Malcolm ... iii
Pitometer Co. ... iii
Potts, Clyde ... ii
Weston & Sampson ... iii
Whitman & Howard ... iii

ENGINES. (See Pumps and Pumping Engines.)

EQUIPMENT. (See Contractors' Equipment.)

ERECTORS, WATER WORKS AND POWER MACHINERY.
Turbine Equipment Co. ... xx

FEED WATER FILTERS.
Ross Valve Mfg. Co. ... xxiv

FEED WATER HEATERS.
Worthington Pump and Machinery Corp. ... vi

FILTRATION PLANT EQUIPMENT.
Builders-Providence, Inc.
Division of Builders Iron Foundry ... xiii
Morris Machine Works ... xix
Ross Valve Mfg. Co. ... xxiv
Wallace & Tiernan Co., Inc. ... xxi

FLEXIBLE JOINTS.
U. S. Pipe and Foundry Co. ... Facing back cover

FLAP VALVES.
Eddy Valve Co. ... xv

FURNACES, ETC.
Atlas Mineral Products Co. ... xvi
Leadite Co., The ... Back cover
Smith Mfg. Co., The A. P. ... xvii

GATE VALVES. (See Valves.)

GUNITE.
National Gunite Contracting Co. ... iii

HOSE, SUCTION AND CONDUCTION.
Edson Corp., The ... xxii

HYDRANTS, FIRE.
Eddy Valve Co. ... xv
Kennedy Valve Mfg. Co. ... xiv
Ludlow Valve Mfg Co. Inc., The ... ix
Rensselaer Valve Co. ... xxiii
Ross Valve Mfg. Co. ... xxiv
Smith Mfg. Co., The A. P. ... xvii
Wood, R. D., Co. ... xxvi

HYDRANT PUMPS.
Edson Corp., The ... xxii

INSTRUMENTS. (See Water Works Instruments.)

LEAD.
National-Boston Lead Co. ... xvi

LEAD PIPE. (See Pipe, Lead.)

LEAD WOOL.
National-Boston Lead Co. ... xvi

LEAK FINDERS.
Pitometer Co. ... iii
Edson Corp., The ... xxii

CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued)*

METERS, WATER AND OIL. Page
Builders-Providence, Inc.
Division of Builders Iron Foundry ... xiii
Hersey Mfg. Co. ... v
Neptune Meter Co. ... vii
Pitometer Co. ... iii
Pittsburgh Equitable Meter Co. ... Following front cover
Worthington Pump and Machinery Corp. ... vi

METER COUPLINGS.
Ford Meter Box Co. ... xvii

METERS (VENTURI TYPE).
Builders-Providence, Inc.
Division of Builders Iron Foundry ... xiii

METER BOXES.
Bingham and Taylor ... iv
Ford Meter Box Co. ... xvii

METER TESTERS.
Ford Meter Box Co. ... xvii

OIL ENGINES, DIESEL.
Fairbanks-Morse & Co. ... xii
Worthington Pump and Machinery Corp. ... vi

PACKING.
H. D. Jackson ... iii

PIPE, BRASS.
Pierce-Perry Co. ... viii

PIPE, CAST IRON (AND FITTINGS).
Builders-Providence, Inc.
Division of Builders Iron Foundry ... xiii
Cast Iron Pipe Research Assn. ... xxxi
Donaldson Iron Co. ... xvii
U. S. Cast Iron Pipe and Foundry Co. ... Facing back cover
Warren Foundry and Pipe Corp. ... xxii
Wood, R. D., Co. ... xxvi

PIPE, CEMENT LINED.
Cement Line Pipe Co. ... viii
Eureka Pipe Co., Inc. ... viii

PIPE, CONCRETE.
Lock Joint Pipe Co. ... Facing front cover

PIPE CUTTING MACHINES.
Smith Mfg. Co., The A. P. ... xvii

PIPE JOINTING MATERIAL.
Atlas Mineral Products Co. ... xvi
Hydraulic Development Co. ... x
Leadite Co., The ... Back cover

PIPE, LEAD.
National-Boston Lead Co. ... xvi

PIPE LINING.
Wailes Dove-Hermiston ... xxiii

PIPE, TRANSITE.
Johns-Manville ... xi

PIPE, WROUGHT IRON AND STEEL.
Pierce-Perry Co. ... viii

PLUG VALVES.
Eddy Valve Co. ... xv

PITOMETERS.
Pitometer Co. ... iii

PORTABLE AIR COMPRESSORS. (See Air Compressors.)

PRESSURE REGULATORS.
Ross Valve Mfg. Co. ... xxiv

CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued)*

Page

PROVERS, WATER.
Pittsburgh Equitable Meter Co. ..... Following front cover

PUMPS AND PUMPING ENGINES.
Edson Corp., The xxii
Fairbanks-Morse & Co. xii
Morris Machine Works xix
Ross Valve Mfg. Co. xxiv
Turbine Equipment Co. xx
Wood, R. D., Co. xxvi
Worthington Pump and Machinery Corp. vi

RATE CONTROLLERS, AND GAUGES.
Builders-Providence, Inc.
Division of Builders Iron Foundry xiii

SHEAR GATES.
Eddy Valve Co. xv

SLEEVES, PIPE LINE REPAIR.
Dresser Mfg. Co. ..... Following front cover

SLEEVES, RIVER.
Dresser Mfg. Co. ..... Following front cover

SLEEVES AND VALVES, TAPPING.
Eddy Valve Co. xv
Ludlow Valve Mfg. Co. Inc., The ix
Rensselaer Valve Co. xxiii
Smith Mfg. Co., The A. P. xvii

SUPPLIES AND TOOLS.
Hays Mfg. Co. xviii
Leadite Co., The ..... Back cover
Pierce-Perry Co. viii
Smith Mfg. Co., The A. P. xvii

TAPPING MACHINES.
Hays Mfg. Co. xviii
Red Hed Mfg. Co. xxv
Smith Mfg. Co., The A. P. xvii

TAPPING SLEEVES. (See Sleeves and Valves, Tapping.)

VALVE BOXES.
Bingham and Taylor iv
Eddy Valve Co. xv
Ford Meter Box Co. xvii
Rensselaer Valve Co. xxiii
Wood, R. D., Co. xxvi

VALVE INSERTING MACHINES.
Smith Mfg. Co., The A. P. xvii

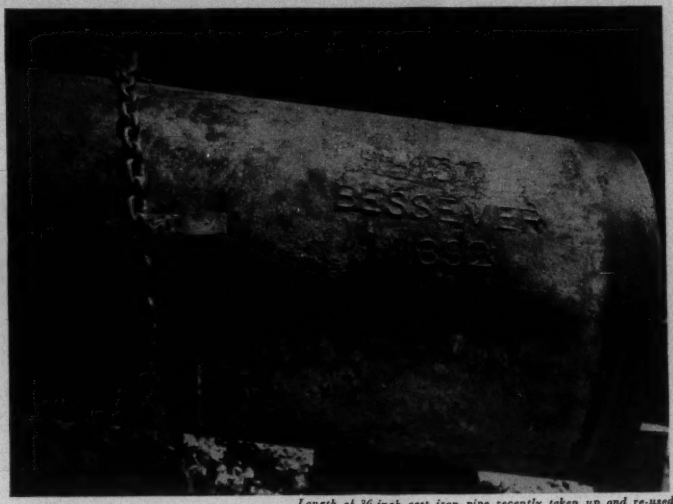
VALVES, GATE.
Eddy Valve Co. xv
Kennedy Valve Mfg. Co. xiv
Rensselaer Valve Co. xxiii
Smith Mfg. Co., The A. P. xvii
Wood, R. D., Co. xxvi

VALVES, REGULATING.
Ross Valve Mfg. Co. xxiv

WATER WASTE DETECTION.
Pitometer Co. iii

WELL CONNECTIONS.
Red Hed Mfg. Co. xxv

WROUGHT IRON PIPE. (See Pipe, Wrought Iron and Steel.)



Length of 36-inch cast iron pipe recently taken up and re-used elsewhere in Fort Worth, Texas. Note date mark on pipe

Salvaged and re-used because it's CAST IRON

THE salvage or re-use value of cast iron mains which must be abandoned or relocated has always been an economy feature of cast iron pipe. Today it is of prime importance. Cast iron pipe will serve out its full century of useful life, either in its original location (which may be temporary) or relaid elsewhere, even in another city. Many instances are on record of old cast iron mains taken up and re-used, or sold to other cities for re-use, or sold as scrap.

For example, the City of Fort Worth, Texas, was recently required by the State Highway Department to relocate a 36-inch cast iron main which has been in service about 40 years. The pipe was taken up, found in fine condition, moved to a new location and re-used.

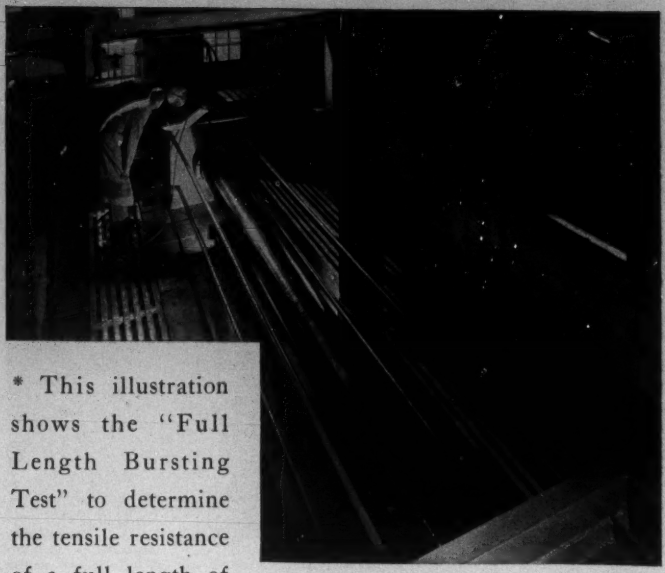
It is impossible to foretell future requirements or population shifts in metropolitan cities but any public official can be sure that, when water or sewer mains must be abandoned or re-routed, the pipe can be salvaged or re-used, if it is cast iron pipe.

Pipe bearing this mark is cast iron pipe. TRADE MARK REG. Available in diameters from 1¼ to 84 inches.

Cast Iron Pipe Research Association, Thomas F. Wolfe, Research Engineer, 1015 Peoples Gas Building, Chicago, Illinois

CAST IRON PIPE

PUBLIC TAX SAVER NO. 1



* This illustration shows the "Full Length Bursting Test" to determine the tensile resistance of a full length of pipe. The pipe is subjected to progressively increased hydrostatic pressure until failure occurs. Although not a required acceptance test, it is one of the additional tests regularly made by this Company to further check and maintain the quality of its pipe so that it will adequately meet severe service requirements. *United States Pipe and Foundry Co., General Offices: Burlington, New Jersey.* Sales Offices in Principal Cities.

*** One of a series of controls in operation at each of our plants, beginning with inspection and analysis of raw materials and ending with tests of the finished product, all subject to the central control of our headquarters staff at Burlington.**

U.S.
cast iron
PIPE
Centrifugally or Pit Cast for water, gas, sewerage, drainage and industrial services.

The Journal of the New England Water Works Association

is a quarterly publication, containing the papers read at the meetings, together with reports of the discussions. Many of the contributions are from writers of the highest standing in their profession. It affords a convenient medium for the interchange of information and experience between the members, who are so widely separated as to find frequent meetings an impossibility. Its success has more than met the expectation of its projectors; there is a large and increasing demand for its issues, and every addition to its subscription list is a material aid in extending its field of usefulness.

All members of the Association receive the JOURNAL for two dollars per annum which sum is included in their annual dues; to all others the subscription is four dollars per annum.

TO ADVERTISERS

THE attention of parties dealing in goods used by Water Departments is called the JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION as an advertising medium.

Its subscribers include the principal WATER WORKS ENGINEERS and CONTRACTORS in the United States. The paid circulation is **1000** COPIES.

Being filled with original matter of the greatest interest to Water Works officials it is PRESERVED and constantly REFERRED TO BY THEM, and advertisers are thus more certain to REACH BUYERS than by any other means.

The JOURNAL is not published as a means of revenue, advertisements being inserted solely to help meet the large expense of publication.

ADVERTISING RATES

One page, one year, four insertions	Eighty Dollars
One-half page, one year, four insertions	Fifty-six Dollars
One-fourth page, one year, four insertions	Thirty-six Dollars
Card size, one year, four insertions	Twelve Dollars
One page, single insertion	Forty Dollars
One-half page, single insertion	Thirty Dollars
One-fourth page, single insertion	Twenty Dollars

Size of page, 4½ x 7½ net.

A sample copy will be sent on application.

For further information, address the Advertising Agent,

(Mrs.) MARCELLA S. NORINS,
613 STATLER BUILDING,
BOSTON, MASS.

LEADITE

Trade Mark Registered U.S. Pat. Office

COSTS ARE REDUCED WHEN *LEADITE* IS USED

Of course, the greatest advantage in using LEADITE, is, that it makes a good, tight joint,—and thus reduces leakage to a minimum,—but LEADITE also offers the following advantages, which are worthy of serious consideration: Saves caulking expenses—Reduces cost of digging large bell-holes —Saves in cost of material—Reduces time required for pumping "wet trenches"—Saves time in preparation—Saves time in handling on the job—Saves in freight and hauling charges.

Another point, LEADITE saves "interest charges" by speeding up the completion of the water line.

The true value of LEADITE is best indicated by the fact that it has been used on THOUSANDS OF MILES of Water Mains,—all over this Country, as well as in many Overseas Countries.

The Pioneer self-caulking material for c. i. pipe,
Tested and used for over 40 years,
Saves at least 75%.

THE LEADITE COMPANY

Girard Trust Company Building — Philadelphia, Penna.